THE USE OF TERRESTRIAL TEST SITES AND AIRCRAFT FLIGHTS IN PREPARING FOR REMOTE SENSING FROM EARTH ORBITAL SPACECRAFT*

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The National Aeronautics and Space Administration is engaged currently in the planning of scientific payloads for future earth and planetary (Mars, Venus, Moon) orbital spacecraft. The instruments which would make up the scientific payload are remote sensors, including detectors to measure infrared, microwave, X-ray and gamma ray emittance; active radar systems, multiband photography; gravity, magnetic, and other sensors. Because the scientific applications of remote sensors are not well understood, the NASA is now engaged in a comprehensive aircraft flight program over known ground sites to test these new and hopefully very useful tools.

The heavily-instrumented NASA-MSC Convair 240A, equipped for full in-flight monitoring and data recording, is ideally suited for the initial phases of the test-site survey program at altitudes of less than 20,000 feet; present equipment includes two scanning systems which record infrared responses in the 4.5-5.5 and 8-13$\mu$ ranges.

Pisgah Crater and adjoining lava flows, California, were selected for initial NASA remote sensing surveys to provide infrared imagery. Relationship of surface temperatures, microrelief, and reflectances of various lithologies to film density on infrared images suggests that unconsolidated materials possess lower thermal inertia and for equal quantities of solar radiation emit larger quantities of infrared energy than consolidated materials. Density of infrared images differs for different angles of view, perhaps more for rough surfaces than for smooth. Such variations in radiation may be observed from airborne platforms.

NASA TMX 57238



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*Prepared for technical papers that will later be published in the Proceedings of the American Astronautical Society

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Publication is authorized by the Director, Manned Space Science Program (NASA) and by the Director, U.S. Geological Survey

Addenda to preprint of paper titled "The use of terrestrial test sites and aircraft flights in preparing for remote sensing from earth orbital spacecraft" by Peter C. Badgley, Leo Childs, and William A. Fischer.

Fig. 21 Index Map Showing Location of Pisgah Crater Area

Fig. 22 Index aerial view of Pisgah Crater area. Large rectangles are fundamental test site. Small squares 1-5 are special-purpose radar sites. Pisgah basalt lava flows are larger dark areas to the north; Sunshine flows are to the south. Salient geologic features include: A) Pisgah Crater, B) Sunshine Crater, C) bisected Lavic Crater (all pyroclastic cones), D) aa-textured flows, E) pahoehoe-textured flows, F) tonal differences indicating compositional and age differences in Sunshine flows, G) Pisgah fault scarp, H) Lavic Lake playa, I) basalt fragments near southern end of Pisgah flows, overlying mud-cracked silty-clay surface of playa, J) pepper-salt pattern indicating presence of silt pockets in surface of basalt flow, K) Sunshine Range composed of andesite and dacite porphries and lesser amounts of quartz monzonite, L) older and Quaternary aluvium, and M) recent fan deposits.

Fig. 24 Chart showing radiant temperatures of various materials during the period 0600 to 0800, February 13, 1965, together with the temperature of the air and sky and other meteorological parameters. Underscored numerals indicate film density values of infrared images of various materials. The materials to which they refer and the time the images were produced are shown with "x"'s. Density values not to scale. Based on preliminary interpretation of data.

Fig. 27 Sections selected for each lithology are those most closely approximating the mean surface area of all samples for each lithology.

Fig. 29 Range in change of image density away from centerline of image of several lithologies, plotted against surface irregularity (ratio of mean surface area of approximately 16 samples of each lithology to area of an equidimensional plane). Determined from selected infrared images flown February 13-14, 1965, and preliminary interpretation of data.

## INTRODUCTION

The National Aeronautics and Space Administration is currently evaluating a number of new and newly refined instruments for use in exploring the earth and planetary surfaces from orbiting spacecraft. These vehicles are expected to play a role analagous to that of aerial survey aircraft in the natural resource field.

The instruments which would make up the payload, often referred to as "remote sensors", include devices that are sensitive to force fields, such as gravity gradient systems and devices that record the reflection or emission of electromagnetic energy. Both passive (those that rely on natural sources of illumination, such as the sun) and active (those that utilize an artificial source of illumination) electromagnetic sensors are under consideration. Investigations relating to force field sensors are in an inceptive stage and are not further discussed in this paper.

Each type of surface material (e.g. soils, rocks, vegetation and other forms of life, etc.) absorbs and reflects solar energy in a characteristic manner depending upon its atomic and molecular structure. In addition, a certain amount of internal energy is emitted which is partially independent of the solar flux. The absorbed, reflected and emitted energy can be detected by remote sensing instruments in terms of characteristic spectral signatures and images. These signatures can usually be correlated with known rock, soil, crop, and other conditions. The relationship to specific terrain features can be more closely established by judiciously correlating a group of diverse signatures, each obtained simultaneously by a different remote sensor.

## CHARACTERISTICS OF ELECTROMAGNETIC SPECTRUM

Sensors which respond to energy in the gamma ray, ultraviolet, visible, infrared, and radio parts of the spectrum are being considered for use in the NASA program. Selection of the specific parts of the electromagnetic spectrum to be utilized in these investigations is governed largely by the photon energy, frequency, and atmospheric transmission characteristics of the spectrum (fig. 1). The exploration role that sensors will be assigned on terrestrial or lunar surveys is similarly dictated by spectrum characteristics, principally atmospheric transmission. Some of the remote sensors responding to various parts of the spectrum and their possible exploration applications are illustrated (figs. 2 and 3).

### Basic Preflight Studies Underway

Chemical composition, surface irregularity, degree of consolidation and moisture content are among the parameters that are known to affect the records obtained by electromagnetic remote sensing devices. Full interpretation of sensor records requires therefore, that these effects be known and studied quantitatively. A number of fundamental laboratory studies concerned with these effects are underway. Laboratory studies are being supplemented by detailed studies of a number of test sites in the United States and elsewhere. These test site studies form a very significant part of NASA's pre-spaceflight program. Detailed ground study of these test areas, coupled with preliminary remote sensing surveys from aircraft, are being undertaken by various cooperating organizations. An evaluation of the scientific applications of radar for earth and planetary surface analysis is currently underway (fig. 4). Similar steps are also underway for each type of promising remote sensor. These basic studies should serve to:

1. advance our knowledge of the fundamental effects of various terrain parameters on sensor records.

2. provide a means of calibrating data returned from earth-orbiting sensors (the areas studied are of sufficient size to be resolved from space).

3. test the operation of the sensing equipment for earth orbital flights as well as for later planetary missions.

4. enable us to refine our data handling and interpretation techniques.

The use of aircraft flights over known calibrated ground sites is a very important phase of these basic pre-spaceflight studies (fig. 5). More details on the NASA aircraft facilities being used are described in the following section of this paper. Eventually the jump to spacecraft must occur because aircraft platforms will not be available in orbit about the Moon and other planets. There is of course great merit in viewing the Earth itself from orbital altitudes. Many terrestrial features such as crops, water resources, coastlines and oceanic phenomena are transient in nature and therefore require repeated observations. These may be more readily available in the future via operational spacecraft than by repeated aircraft coverage. Many laymen do not realize that the U.S. Government and industry alone spend on the order of 3 - 5 billion dollars annually on aerial surveys (domestic and overseas operations) according to a recent estimate. Most aerial surveys are one-time flights and do not provide periodic or continuous coverage of transient features. The entire battery of remote sensors designed for terrestrial and planetary surface study constitutes a vast data-gathering system. The applications of this information present an exciting challenge to all branches of earth science.

## Nature of Test Sites

The use of calibrated ground test sites is an important phase of the remote sensor evaluation program being conducted by NASA. Two types of test sites are being studied: 1) fundamental sites and 2) extended sites (fig. 6). The fundamental sites are small in area and considerable ground data already exists for them. They are generally applicable to only a single user discipline. The extended sites are larger in size, also quite well known insofar as ground data is concerned, and contain a number of fundamental sites for various user disciplines. Special guidelines for test site selection were used (figs. 7a, 7b and 8) and some of the test sites already have been selected and are under study.

## Relationship of Remote Sensors to Manned Earth Orbital Missions

The remote sensor instruments being studied by NASA are particularly suitable for payloads on the potential earth and lunar orbital missions (fig. 10). The relationship of this type of experiment to other experimental areas is also being considered for manned earth orbital flights.

# AIRCRAFT IMPLEMENTATION

A basic requirement of the feasibility test program is the simultaneous sensing of the test sites by as many of the sensor systems as possible. Therefore, it is highly desirable to conduct all experiments with the same aircraft. To date only three aircraft have been utilized. All radar data has been acquired by a JC-131B aircraft belonging to the Aeronautical Systems Division, WPAFB, and a WV-2 aircraft belonging to the Naval Research Laboratory. These two aircraft were chosen on the basis of their availability and the characteristics of their existing radar instrumentation. The WPAFB aircraft is equipped with a brute-force type Ka band side-looking radar which registers both sides of the line of flight. The average recording resolution is on the order of 50 feet or less. The NRL aircraft is equipped with four different pulsed coherent radar systems transmitting at P band (428 MC), L band (1225 MC), C band (4455 MC), and X band (8910 MC). Additional radar equipment will be utilized if the investigations require it. It is intended to install all other compatible sensor systems in the NASA-MSC Convair 240A (fig. 12). This aircraft is ideally suited for the initial phases of the test-site survey program which are to be conducted at altitudes of 20,000 feet and below. Eventually, aircraft with higher altitude and longer range capabilities will be utilized. The NASA Convair 990 is expected to be brought into the program in 1966. As the investigations progress, it is anticipated that operations at altitudes up to 82,000 feet will be performed.

The NASA-MSC Convair 240 aircraft has been heavily instrumented as a test for conducting a wide variety of electronic and electro-optical experiments (fig. 13). Basically, the instrumentation provides highly controlled power for the experiments and full in-flight monitoring and data recording of all events. All flight parameters are continuously displayed (fig. 14) and recorded at one-second intervals by the data-recording camera system (fig. 15). All data from the various sensors is indexed together by a time signal and frame number of the master survey camera for ease of processing and retrieval.

A number of the sensor systems, such as the in-flight controls and data recording system of the NASA-USGS infrared scanner (figs. 16 and 17), already have been installed; others will be installed as they become available. The present equipment consists of two scanning systems which record the infrared responses in the 4.5-5.5 and 8-13$\mu$ ranges. The signals are recorded as photographic images on 35 and 70 mm film. Ultimately this equipment will be modified to record all responses on magnetic tape to ensure maximum interpretability.

A T-11 mapping camera and an A-28 gyro-stabilized mount have been installed (fig. 18). This equipment provides conventional photography for indexing and control of all sensor events with ground-position information and general terrain features. The data from all other sensors can be correlated with this photography for any desired time frame.

Two additional A-28 gyro-stabilized mounts will be installed (fig. 19) and a multispectral camera will be installed in one of these mounts. This camera contains nine identical lenses filtered to record the responses from 3800Å to 9000Å in discrete spectral ranges. This equipment will be operational by April 1965. The other A-28 mount will contain an infrared spectrometer to record the spectral responses in the 7-30μ range. This equipment will be operational in July 1965.

In addition to the sensor systems mentioned above, a passive microwave receiver system is expected to be operational in the CV240 aircraft by mid-summer 1965.

A summary of the investigator teams participating in the NASA remote sensing feasibility program (fig. 20) appears in the following section of this paper which describes some of the preliminary work of the infrared team.

INFRARED AERIAL SURVEY AT PISGAH CRATER

Initial surveys utilizing the NASA remote sensing aircraft were undertaken from February 9 to February 17, 1965, at Pisgah Crater, San Bernardino County, California. Sensors aboard the aircraft utilized in these surveys included a Reconofax 4 infrared scanner, operating in the 8-13$\mu$ part of the spectrum, and a AAS-5 scanner, filtered so as to record energy in the 4.5-5.5$\mu$ part of the spectrum.

Pisgah Crater rubble cone and adjoining lava flows (figs. 21, 22 and 23) were selected as the site of the initial surveys for the following reasons:

1. the rocks are relatively fresh and largely unaffected by weathering,

2. the area is largely devoid of vegetation,

3. rocks having similar chemical composition occur here in a variety of physical conditions (rough, smooth surface to consolidated and loose),

4. the area is free of snow for most of the year,

5. the area is readily accessible by land and air,

6. geologic maps of the area are available, and

7. support facilities, such as photographic laboratories, are available at nearby NASA installations.

The principal objectives of the initial surveys were testing the airborne and related field monitoring equipment under operational conditions and developing field methods for describing the surface of various rock units in a statistically valid manner and in terms meaningful to the interpretation of the infrared records.

The initial surveys and related field studies have also contributed to several long-range objectives of our program by:

1. permitting an assessment of the value of infrared records in measuring the differences in thermal inertia of various earth materials and relating these observations and measurements to differences in consolidation and surface irregularity of the various materials,

2. permitting an assessment of the effects of different angles of view on infrared records and relating these observations to surface irregularity,

3. permitting an assessment of the geologic value of simultaneous observations of solar absorption and infrared emission,

4. permitting a preliminary assessment of the geologic value of observations of the spectral distribution of infrared energy emitted by various rock types present in the area, and

5. permitting a preliminary appraisal of the effects of altitude on infrared records.

In preparation for the remote sensing surveys, aerial photographs were taken at scales of 1:4000-1:8000, control points established and targeted, and topographic profiles of selected areas compiled at scales of 1:600. The targeted control points were used in the preparation of the topographic profiles and will be of additional value in calibrating the various sensing instruments and in relating various remote sensing images to one another.

During the period of aircraft flight, the temperature of each of the major rock units (Seven gross lithologic units were studied in the Pisgah area. These units were:

1) aa, rough-surfaced or granular basaltic lava,

2) pahoehoe, basaltic lava having a relatively smooth or vesicular surface,

3) desert pavement mosaic of basalt fragments and areas covered with loose fragments of basaltic lava,

4) cinders, blocks and ash of rubble cone,

5) surficial materials, chiefly calcareous silt and quartz sand,

6) alluvial fan material ranging from silt to boulders, of diverse composition, and

7) playa deposits, mostly silt and clay.)

was monitored (figs. 23, 24 and 25) to provide calibration for the aerial infrared images and basic information relating to the thermal properties of the rock units themselves. These measurements demonstrate that the various units differ from one another in thermal properties. Cinders, for example, are characterized by low radiant temperature during nighttime hours; a rapid rate of change in temperature at dawn, signifying low thermal inertia; and relatively high radiant temperature in daylight hours. These characteristics contrast strongly with characterisitcs of aa and pahoehoe lavas, which have lower rates of change and radiant temperatures more nearly approaching the temperature of the air surrounding them. Close examination of the temperature records suggest that each of the units is distinguishable and possibly identifiable, by analysis of its thermal behavior.

The radiant temperatures of each of these units were recorded several times on aerial infrared images during the period of time represented in figure 24. While only preliminary analyses of these records have been made, these analyses suggest that the thermal properties of the various units may be deduced from sequential airborne infrared images provided appropriate thermal reference is available from ground control or possibly from an instrument calibration system. Some preliminary results of the analysis of the airborne infrared records are also shown in figure 24.

In addition to monitoring the temperatures of various units during periods of aircraft flight, measurements were made and samples collected to provide data relevant to other parameters which may affect the way in which various surfaces are registered on infrared images. Profiles of segments of the surface were among the data obtained in the field. These profiles were measured in two directions at a spacing of three feet in a rectangular grid system of 225 $ft.^2$ for each lithologic unit (fig. 26). Estimates of the surface irregularity or microrelief were made for each sample location in five lithologic units by measurement of the profile surface length (fig. 27 and 28) and estimation of the total surface area. The ratio of surface area of sample to the area of an equidimensional plane is considered here an index of surface irregularity. The mean surface irregularity of 16 samples of each lithology was plotted against change in infrared image density per degree of arc (fig. 29) to determine the relationship between surface irregularity and image density.

These relationships suggest that, in general, the total radiating surface, and hence the total energy visible to the detector at any one instant of time, diminishes more rapidly for irregular surfaces than for relatively smooth surfaces with increasingly oblique angles of view.

To evaluate possible geologic significance of observations of the relationship between solar absorption and infrared emission, the film density of the infrared images of the various units was contrasted to their absorption of visible light as determined by colorimetric measurement (fig. 30). The preliminary results of this investigation are shown in figure 31. These observations show that the unconsolidated deposits, cinders and silt, emit significantly more infrared energy when exposed to sunlight than the consolidated lavas, although the cinders and silt reflect more (absorb less) solar energy than the lavas. The data likewise suggest that the irregularly-surfaced aa (fig. 30) emits more radiation relative to its absorption of solar energy than the somewhat less irregularly-surfaced pahoehoe.

Sensor flights were undertaken at altitudes of 1,500 feet above terrain and at 5,000 feet above terrain to obtain preliminary data relating to the effects of increasing altitude on our ability to distinguish various materials. At the present time these images are unevaluated; they will be studied to determine the effects of successively higher flight altitudes.

The spectral distribution of emitted infrared energy in the 5-15μ range was measured in the field with a spectrometer-interferometer (fig. 32). Strong signals and clear records were obtained that seemingly show significant differences in the spectral distribution of energy emitted by the various lithologies. The recorded signals are being processed by a co-adder, computer, and wave analyzer, to determine which of the processing instruments and techniques yield the most meaningful results.

## SUMMARY OF INFRARED SURVEYS

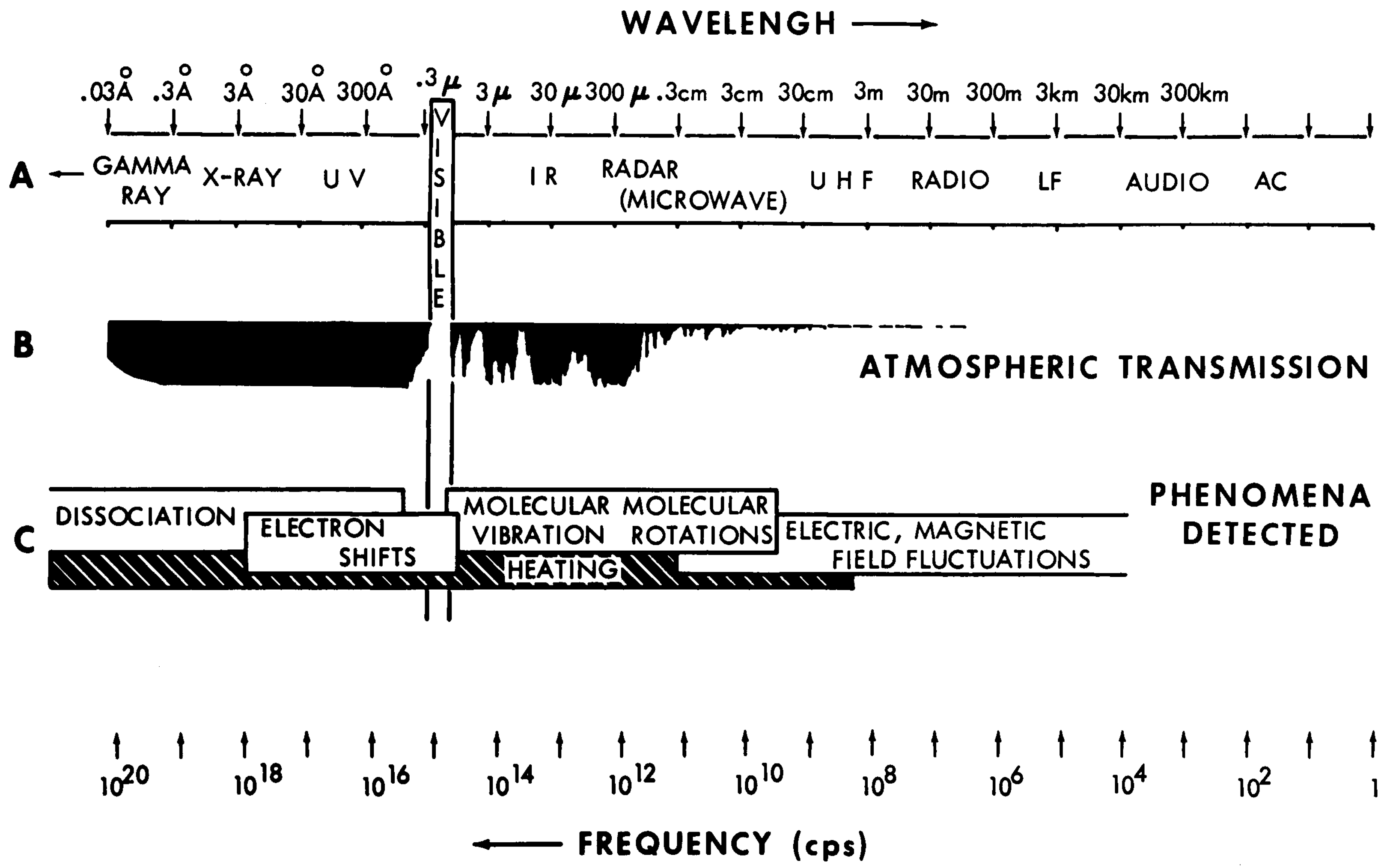
Pisgah Crater and adjoining lava flows, California, were selected for the initial surveys undertaken with the NASA remote sensing aircraft. These surveys were primarily intended to test equipment under field conditions and to provide infrared imagery of the test site at various times of day and from various spatial positions. Field control stations were surveyed and targeted on the surface of the test site to facilitate development of topographic profiles at a scale of 1:600 and to assist in relating various sensor records to one another.

Field measurements of surface temperatures, microrelief, and laboratory measurements of reflectance were contrasted with measurements of film density on infrared images acquired at various times of day. Measurements of microrelief were also contrasted with film densities of various materials imaged at increasingly oblique angles.

Contrast of these various functions suggests that unconsolidated materials possess a lower thermal inertia than consolidated materials; that unconsolidated materials emit larger quantities of infrared energy than consolidated materials when both are subjected to similar quantities of solar radiation; and that the film densities with which objects are recorded on infrared imagery differ with angle of view; commonly the differences are greater for rough surface than for smooth. These studies also suggest that these relative quantities and changes in relative quantities of radiation may be observed from airborne platforms.

ILLUSTRATIONS

CHARACTERISTICS OF THE ELECTROMAGNETIC SPECTRUM WHICH ARE OF SIGNIFICANCE IN REMOTE EXPLORATION




NASA SM65-15182
3/8/65

Fig. 1 Relationship of Remote Sensor Instruments to the Electromagnetic Spectrum and to Atmospheric Transmission

## FIG. 2 REMOTE SENSOR INSTRUMENTS BEING STUDIED BY NASA AND SOME OF THEIR EXPECTED APPLICATIONS

REMOTE SENSOR INSTRUMENTS

| APPLICATION / EXPERIMENTAL TECHNIQUE | AERONOMY AND METEOROLOGY | AIR POLLUTION | AGRICULTURE/ FORESTRY | GEOLOGY | HYDROLOGY | OCEANOGRAPHY | GEOGRAPHY |
|---|---|---|---|---|---|---|---|
| VISUAL PHOTOGRAPHY | Lighting and Auroral Phenomena | Tracking Pollution Masses | • Crop and Soil Identification • Identification of Plant Vigor and Disease | Identification of Surface Structure | Identification of Drainage Patterns | Identification of Sea State, Beach Erosion, Offshore depth & turbidity | Urban-rural land use, transportation routes &facilities. terrain & vegetation characteristics |
| MULTI-SPECTRAL PHOTOGRAPHY | Noctiluminescent Clouds and Auroral Phenomena | Tracking and Analysis of Pollutant Masses | • Crop and Soil Identification • Identification of Plant Vigor and Disease. | Identification of Surface Features | Soil Moisture Content | Sea Color as Correlated with Productivity | |
| I.R. IMAGERY AND SPECTROSCOPY | • Cloud Motion • Vertical Temperature Profile | • Pollutant Analysis • Tracking Pollution Masses | • Terrain Composition • Plant Vigor and Disease Condition | • Mapping Thermal Anomalies • Mineral Identification | Detection of Areas Cooled by Evaporation | • Mapping of Ocean Currents • Sea-Ice Investigations | Surface energy budgets, near Shore currents land use |
| RADAR IMAGERY | • Cloud Physics • Precipitation | Detection and Tracking of Smoke Plumes | Soil Characteristics | • Surface Roughness • Tectonic Mapping | • Measurement of Soil Moisture Content • Identification of Run-off Slopes | • Sea State • Ice flow and Ice Penetration • Tsunami warning | • Land/Ice Mapping • Cartographic and Geodetic Mapping |
| R.F. REFLECTIVITY | | | Soil Characteristics | Sub-surface Layering Mineral Identification | Moisture Content of Soils | • Sea Ice Thickness and Mapping • Sea State | Land/Ice Mapping and Thickness Penetration of Vegetation Cover |
| PASSIVE MICROWAVE RADIOMETRY & IMAGERY | | | Brightness Temperature Map of Terrain | Dielectric Constant Measurement Indicative of Sub-surface Layering | Snow & ice Surveys | | Snow & ice measurements |
| ABSORPTION SPECTROSCOPY (REMOTE GEO-CHEMICAL SENSING) | | Measurements of Pollutant Circulation Patterns and Concentrations | | Detection of Mineral Deposits Trace Metals, and Oil Fields | | Detection of Concentrations of Surface Marine Flora | |

Fig. 2 Remote Sensor Instruments Being Studied by NASA and Some of Their Expected Applications

| | γ-RAYS | HARD X-RAYS | SOFT X-RAYS | VACUUM ULTRA-VIOLET | NEAR U.V. | VISIBLE | | | INFRARED | | | MICROWAVE | RADAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | PHOTOG U.V. | SPECTRAL VIS. | PHOTOG IR | NEAR INFRARED | MED. INFRARED | FAR INFRARED | | |
| FREQUENCY | $10^{14}$ MC | $10^{13}$ MC | $10^{12}$ MC | $3\times10^{10}$ TO $10^{9}$ MC | $8\times10^{8}$ MC | AROUND $5\times10^{8}$ MC | | | ABOUT $10^{8}$ MC | ABOUT $10^{7}$ MC | ABOUT $10^{6}$ MC | 300 KMC - 0.3 KMC | 20 KMC TO 0.3 KMC |
| WAVE LENGTH | 0.03 A | 0.3 A | 3 TO 100 A | 100 to 3000 A | NEAR 4000 A | 4000 TO 5000 A | 5000 TO 7000A | 7000 A TO 10,000 A | 0.7 TO 4 MICRONS | 4 TO 15 MICRONS | 15 TO 800 MICRONS | 1MM TO 100 CM | K-BAND 1.5 CM TO P-BAND 100 CM |
| ENERGY | $1\times10^{6}$ EV | $5\times10^{4}$ EV | $1\times10^{3}$ EV | 12 EV TO 4 EV | 3 EV | 2.7 TO 1.75 EV | | 1.75 TO 1.25 EV | 1.75 TO 0.3 EV | 0.3 TO 0.08 EV | VERY LOW | VERY LOW | |
| OPERATIONAL MODE | PASSIVE-SCINTILLATION COUNTERS | | | ACTIVE (2000 TO 3900 A) | PASSIVE | GENERALLY PASSIVE | | | REFLECTANCE (SOLAR - ACTIVE) | EMISSION (PASSIVE) | EMISSION (PASSIVE) | PASSIVE OPERATED TUNED TO ONE WAVELENGTH | ACTIVE, CW OR PULSED, TUNED TO ONE WAVE LENGTH |
| ATTENUATION BY THE ATMOSPHERE | EXTREME | ATTENUATION | | 2200 TO 2700 RALEIGH SCATTERINGS 2400 TO 3100 A OZONE STRONGLY ABSORBS | LIMITED ATTENUATION | LIMITED ATTENUATION | GOOD VISIBILITY | BETTER VISIBILITY | EXTREME IN BANDS AT 0.9, 1.1, 1.38, 1.9, 2.7 MICRONS | EXTREME IN BANDS AT 4.3, 6.0, 15.0 MICRONS | EXTREME IN BANDS AT 25 THROUGH 1000 MICRONS | LOW EXCEPT FOR SOME SPECIFIC BANDS | VERY SLIGHT |
| DATA TYPE | ANALOG SIGNAL - FREQUENCY PULSE HEIGHT ANALYSIS | | | PHOTOMULTIPLIER SIGNALS | IMAGE ORTHICONS & FILM | PHOTOGRAPHIC FILM (IMAGING) SPECTRAL SERIES | | | IMAGE & TAPE | RADIOMETER OUTPUT- TAPE | RADIOMETER OUTPUT (TAPE) | RADIOMETER RESPONSE (TAPES) | ANALOG SIGNAL, CAN BE CONVERTED TO IMAGING SYSTEM |
| STORAGE FORMAT | FILMS OR DIGITAL TAPE (NON-IMAGING) | | | FILM OR TAPE (POSSIBLY IMAGING) | FILM OR TAPE | FILMS- WHICH MAY BE READ BY A FLYING SPOT SCANNER-CONVERTED INTO DIGITAL | | | FILMS AFTER AN IMAGING SYSTEM | TAPE-ANALOG SIGNAL | TAPE-ANALOG SIGNAL | OSCILLOSCOPE OR TAPE & FILM FOR STORAGE | OSCILLOGRAPH OR TAPE & FILM FOR STORAGE |
| EFFECTIVE SOURCE DEPTH OF INFORMATION IN RECEIVED SIGNAL | "20 CM OF ROCKS" | ONE TO SEVERAL MICRONS | | ANGSTROMS TO MILLIMETERS | ANGSTROMS OR MILLIMETERS | ONLY ANGSTROMS DEEP IN SOLIDS TO TENS OF METERS DEEP IN WATER ABSORPTION COEFFICIENTS BEST KNOWN OF ANY PART OF THE EM SPECTRUM | | | SOURCE DEPTHS ARE MEASURED IN MICRONS (EVEN FOR WATER), SOME ABSORPTION COEFFICIENTS ARE KNOWN - ATTENUATION IS COMPLETE WITHIN 10 TO 100 MICRONS. | | | UNCERTAIN, SEVERAL CENTIMETERS ONLY | SANDY SOIL / LOAM<br>K-BAND — / —<br>X-BAND 2" / 1"<br>S-BAND 8" / 2"<br>P-BAND 315" / 10" |
| PHENOMENA DETECTED | ATOMIC TRANSITIONS AND INNER ELECTRON SHIFTS | | | OUTER ELECTRON SHIFTS | OUTER ELECTRON SHIFTS | REFLECTION OF VISIBLE LIGHT<br>INCREASED CONTRAST INCREASED HAZE PENETRATION | | | REFLECTANCE OF SOLAR INFRARED-PRINCIPALLY SURFACE EFFECTS, ROUGHNESS | THERMAL MOTION OF ATOMS MODIFIED BY THE VIBRATIONS OF THE MOLECULES & CRYSTAL LATTICES. | | MOLECULAR ROTATIONS IN ATMOSPHERE, SURFACE & SUB-SURFACE EMITTANCE FUNCTIONS OF REFLECTANCE ABSORPTION & TEMPERATURE | BACKSCATTERING BY THE SURFACE; DIELECTRIC CONSTANT, ROUGHNESS, DEPOLARIZATION ARE SIGNIFICANT PARAMETERS. |
| ANALYTICAL END RESULTS | ELEMENTAL ANALYSIS:<br>TOTAL γ-RAY FLUX SPECTRAL γ-RAY FLUX $K^{40}$ U, TH SERIES RADIONUCLIDES, GEOCHEMICAL DATA | | | ELEMENTAL ANALYSIS: ELECTRON TRANSITION FROM GROUND STATE | VALENCE & OXIDATION ELEMENTAL ANALYSIS SOME GAS ANALYSIS | REFLECTANCE VALUES (EITHER POLYCHROMATIC - BROAD BANDPASS, OR SPECTRALLY FILTERED-NARROW BANDPASS. STRUCTURAL STYLE TEXTURAL DATA, MORPHOLOGIC DATA | | | MOLECULAR COMPOSITIONS, THIN GAS LAYERS EMIT AS NARROW SHARP LINES. SOLIDS SHOW BROAD STRUCTURELESS BANDS.<br>TEXTURAL DATA, AND PERHAPS SOME THERMAL RESULTS | | | EMITTANCE OR APPARENT TEMPERATURES DIFFERENCES GEOLOGICAL VALUE UNDEFINED THERMAL, TEXTURAL AND COMPOSITIONAL DATA | SURFACE ROUGHNESS: CONDUCTIVITY AND DIELECTRIC CONSTANT, STRUCTURAL STYLE, TEXTURAL DATA |
| GEOLOGIC MAPPING APPLICATIONS — EARTH ORBIT | NO APPLICATION (DOWNWARD) | | | NO APPLICATION (DOWNWARD) | | USING EXTRAPOLATIONS FROM KNOWN AREAS WILL SHOW DIFFERENCES IN REFLECTIVITY DEPTHS. (SHAPE, SIZE & ASSOCIATIONS FORM THE PRESENT BASIS OF PHOTO INTERPRETATION). | | | MARKEDLY ATTENUATED BY ATMOSPHERE OTHERWISE ONE OBTAINS REFLECTIVITY OF SOLAR RADIATION, ROUGHNESS CRITERIA | ONLY SOME WINDOWS AVAILABLE (8 - 12 μ) RESTRICTS COMPOSITIONS OF SURFICIAL MATERIALS WHICH MAY BE DETERMINED. | NO APPLICATION DOWNWARD | RELATIVELY UNEXPLORED. ROCK DIAGNOSIS BY DIFFERENCE IN APPARENT TEMPERATURE-FUNCTION BOTH OF EMITTANCE & TRUE TEMPERATURE DIFFERENCE | SAME AS FOR LUNAR ORBIT-LITTLE OR NO ATMOSPHERE EFFECT. |
| GEOLOGIC MAPPING APPLICATIONS — LUNAR ORBIT | A. DISTRIBUTION OF NUCLEAR SPECIES U, TH, $K^{40}$ DISTINGUISHING SURFACE ROCK TYPES BY $K^{40}$ CONTENT. $AL^{26}$ $BE^{10}$ MAY BE PRESENT IF SURFACE HAS BEEN SPUTTERED<br>B. ANALYSIS OF A FEW STABLE ELEMENTS | | | ELEMENTAL ANALYSIS OF SURFACE ROCKS & DUST LAYERS | | PHOTOGRAPHY (VISIBLE) CANNOT GIVE AN UNIGUE ANSWER TO FINE-SCALE PHYSICAL OR CHEMICAL COMPOSITIONS UNTIL CALIBRATED AREAS ARE USED. ONE CAN ONLY INFER COMPOSITIONS OF LAYERS AND DISTRIBUTIONS OF SHAPES LARGER THAN THE LIMIT OF RESOLUTION | | | SENSITIVITY TO SOLAR REFLECTIVITIES INCREASED BECAUSE OF APSENCE OF ATMOSPHERE. | SURFACE ROCK DUST CHEMICAL COMPOSITION OR PHYSICAL CHARACTERISTICS, APPARENT TEMPERATURE RANGE AND COMPOSITIONS NOT LIMITED BY ATMOSPHERE | REGION- UNEXPLORED FOR GEOSCIENCE VALUE. | NEAR-SURFACE AND SUB-SURFACE TEMPERATURE, TEMPERATURE GRADIENT. | ROUGHNESS CRITERIA-PERHAPS LAYERING IN DEPTH (10-1000 CM). COMPOSITION, DIELECTRIC CONSTANT, & PARTICLE SIZE DIFFERENCES. |
| CONTRIBUTION TO MAJOR LUNAR PROBLEMS | COMPOSITION OF LUNAR SURFACE AND INTERIOR, CONTENT OF RADIOACTIVE ELEMENTS AND MINERALS, SURVEY OF LUNAR RESOURCES, CRATER FORMATION; i.e. VOLCANIC ACTION VS. FALLING METEORITES, EXTENT OF LUNAR RAYS, DUST LAYER DEPTH, BRIGHTNESS VS. NUMBER OF SECONDARY CRATERS, BEARING STRENGTH OF THE LUNAR SURFACE, DENSITY OF SMALL CRATERS. | | | | | | | | THERMAL STATE OF LUNAR SURFACE, THERMAL MAPPING DATA, NATURE OF DARK SPOTS, i.e. LAVA LAKEBEDS. | | | | |
| IMPORTANT TERRESTRIAL APPLICATIONS | | | | DATA RETURNS FOR STUDY OF METROPOLITAN GROWTH<br>STUDY OF AIR POLLUTION<br>STUDY OF WATER RESOURCES, RELATIONSHIP TO INDUSTRIAL GROWTH AND GENERAL AVAILABILITY; OTHER PREDICTIONS IN HYDROLOGY, e.g. PRECIPITATION, STREAM-FLOW, AND GROUND-WATER LEVELS<br>OPTIMUM USE OF HABITABLE LAND<br>DATA SYSTEM FOR AGRICULTURAL RESOURCE SURVEYS AND CROP PREDICTIONS<br>SPACE DERIVED EARTH DATA FOR USE IN INDUSTRIAL REGIONS AND UNDERDEVELOPED COUNTRIES<br>SYNOPTIC ANALYSIS OF SEA STATE, AIR SEA INTERACTION, ETC.<br>WEATHER FORECASTING AND AIR - MASS FLOWS<br>WATER DRAINAGE, e.g. $H_2O$ CONTENT OF LAND, SOILS | | | | | | | | | |

Fig. 3 Chart Showing Some Characteristics of Parts of the Electromagnetic Spectrum, Some Operational Characteristics of Devices Sensitive to Radiation in Various Parts of the Spectrum, and Some Potential Applications of Data to be Gathered by These Sensors

## DEVELOPMENT OF RADAR EXPERIMENT CAPABILITIES FOR EARTH, LUNAR, AND PLANETARY ORBITAL MISSIONS

| TASK | ACTIVE PARTICIPANTS |
| --- | --- |
| DECLASSIFICATION OF EXISTING RADAR AND MICROWAVE IMAGERY | B. SCHEPS - US ARMY<br>H. CAMERON - ACADIA UNIV. (CAN. & U.K. DATA)<br>NAT. ACADEMY OF SCIENCE COMM ON REMOTE SENSING |
| STUDY OF EXISTING RADAR RETURN DATA AND PUBLICATION OF SCIENTIFIC VALUE | UNIV OF KANSAS - SIMONETT, DELLWIG<br>OHIO STATE UNIV - SCHULTZ, PINCUS<br>ACADIA UNIV - CAMERON<br>US ARMY - SCHEPS |
| LABORATORY AND MODELING STUDIES OF RADAR AND RADIOMETRY RESPONSES OF SIMULATED TERRAIN | OHIO STATE - PEAKE<br>US ARMY (W.E.S.) - DAVIS<br>UNIV KANSAS |
| AIRBORNE AND ROCKET RADAR DATA RETURNS AND ANALYSIS OVER PRESELECTED TERRESTRIAL TEST SITES | UNIV KANSAS - MOORE<br>NAVAL RESEARCH LAB - MACDONALD<br>JOHNS HOPKINS (APL) - KATZ<br>USAF (WRIGHT-PATTERSON) - US ARMY (GIMRADA)<br>JPL - BROWN, BARATH |
| INSTRUMENT SPECIFICATIONS AND DEVELOPMENT FOR ORBITING EXPS. | JPL - BARATH<br>UNIV KANSAS - MOORE<br>UNIV MICHIGAN - BROWN |

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Fig. 4 An Illustration of the Steps Involved in Proving Out the Capabilities of Remote Sensing Instruments for Orbital Missions

| CURRENT - 1968 | 1968 - 72 | 1969 - 70 |
|---|---|---|
| REMOTE SENSOR GEOLOGIC MAPPING CAPABILITY:<br><br>AERIAL OVERFLIGHT OF TERRESTRIAL & OCEANIC SITES TO DETERMINE SCIENTIFIC SIGNIFICANCE OF MULTISPECTRAL RESPONSES<br>PLUS<br>ASSOCIATED "GROUND TRUTH" CALIBRATION IN LAB & FIELD | EARTH ORBITAL OVERFLIGHT OF SAME GEOLOGIC TEST SITES:<br><br>WILL PERMIT ADDITIONAL CALIBRATION OF SENSORS FROM ORBITAL ALTITUDES | LUNAR & PLANETARY ORBITAL SCIENTIFIC SURVEYS CARRYING MANY OF SAME SENSORS USED IN EARTH ORBIT.<br><br>A.E.S. GROUND TRAVERSES PROVIDE ADDITIONAL "GROUND TRUTH" CALIBRATION |

Fig. 5 Sequential Relationship of Remote Sensor Equipped Aircraft Flights to Subsequent Orbital Flights

# TYPES OF TEST SITES BEING STUDIED BY NASA

## I FUNDAMENTAL (6 CATEGORIES)

1. LUNAR ANALOG
2. GEOLOGY
3. AGRICULTURE
4. FORESTRY
5. OCEANOGRAPHY / MARINE TECHNOLOGY
6. GEOGRAPHY

## II EXTENDED

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Fig. 6 Types of Test Sites Being Studied by NASA

# GUIDELINES BEING USED BY NASA IN SELECTING TEST SITES FOR REMOTE SENSOR EVALUATION

## I FUNDAMENTAL TEST SITES SHOULD BE:

1. WELL KNOWN THROUGH DETAILED CONVENTIONAL (GROUND AND / OR AERIAL) STUDIES / MAPPING
2. UNIFORM WITH RESPECT TO FEATURES BEING STUDIED AND RESOLUTION OF INSTRUMENTS
3. AMENABLE TO STUDY BY ALL OR MOST REMOTE SENSORS
4. READILY ACCESSIBLE
5. SMALL IN AREA

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Fig. 7a,b Guidelines Used by NASA to Select Test Sites for Remote Sensor Evaluation

# GUIDELINES BEING USED BY NASA IN SELECTING TEST SITES FOR REMOTE SENSOR EVALUATION

## II EXTENDED TEST SITES SHOULD BE:

1. REASONABLY WELL KNOWN
2. LARGE ENOUGH FOR BROAD SCALE TEST OF REMOTE SENSORS OVER WIDE RANGE OF FEATURES OR CONDITIONS, YET SMALL ENOUGH TO BE CONVENIENTLY STUDIED
3. OF INTEREST TO ALL OR MOST USER AREAS
4. ACCESSABLE SO THAT NECESSARY GROUND CHECKS CAN EASILY BE MADE

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Fig. 7b

# GUIDELINES FOR SELECTING TERRESTRIAL GEOLOGIC TEST SITES WHICH WILL BE USED IN EVALUATING LUNAR REMOTE SENSING APPLICATIONS

1. SHOULD INCLUDE SEVERAL LUNAR ROCK TYPES
2. LARGE SEGMENTS OF THE TERRAIN IN EACH SITE SHOULD BE UNIFORM CHEMICALLY AND PHYSICALLY
3. FREE FROM VEGETATION
4. RELATIVELY FLAT, UNIFORM ELEVATIONS
5. LOWER ALTITUDES, FAVORABLE CLIMATE FOR ALL YEAR STUDY PURPOSES
6. LUNAR ANALOG GEOLOGIC SITUATIONS (VOLCANIC CONES, LAVA FLOWS, LARGE IMPACT AREAS, EJECTA BLANKETS ETC.)

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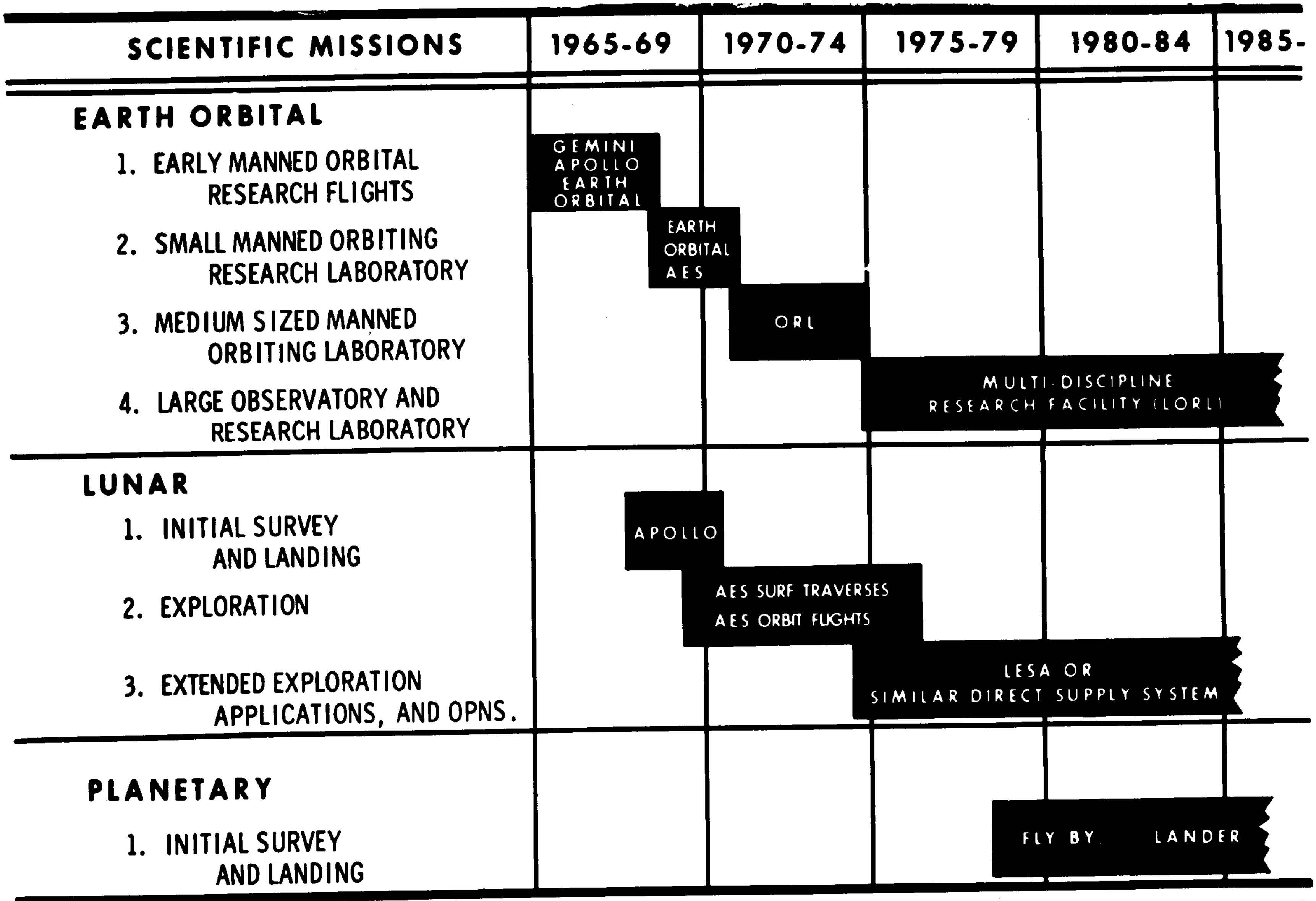
Rev. 3-3-65

Fig. 8 Guidelines for Selecting Terrestrial Geologic Test Sites Which Will be Used In Evaluating Lunar Remote Sensing Applications

# POSSIBLE MANNED SCIENTIFIC MISSIONS

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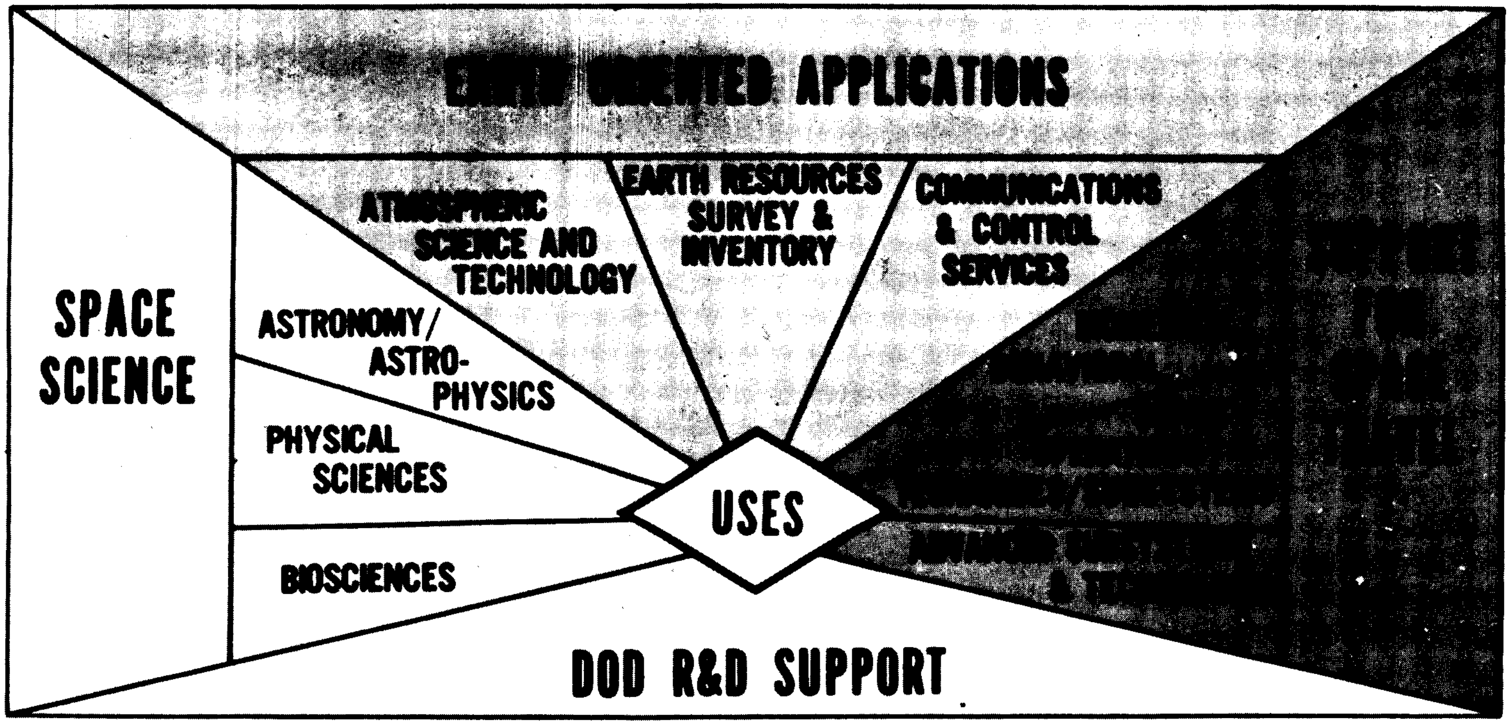
3/8/65

Fig. 10 Relationship of Remote Sensor Developments to Potential Manned Scientific Missions of the Future

## MANNED EARTH ORBITAL EXPERIMENT PROGRAM

# MAJOR APPLICATIONS




# EARTH ORIENTED APPLICATIONS-DETAIL

**ATMOSPHERIC SCIENCE AND TECHNOLOGY**

- AERONOMY/METEOROLOGY
- AIR POLLUTION

**COMMUNICATIONS AND CONTROL SERVICES**

- COMMUNICATIONS
- NAVIGATION/TRAFFIC CONTROL
- ARMS CONTROL

**EARTH RESOURCES SURVEY & INVENTORY**

- AGRICULTURE/FORESTRY
- GEOLOGY/HYDROLOGY
- OCEANOGRAPHY
- GEOGRAPHY/CARTOGRAPHY

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Fig. 11 Relationship of Remote Sensor Instruments (Earth Resources Area) to Other Manned Earth Orbital Experiment Areas

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Fig. 12 THE NASA-MSC REMOTE SENSOR EXPERIMENT AIRCRAFT

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Fig. 13 GENERAL ARRANGEMENT OF THE MASTER CONTROL CENTER FOR REMOTE SENSOR EXPERIMENTS

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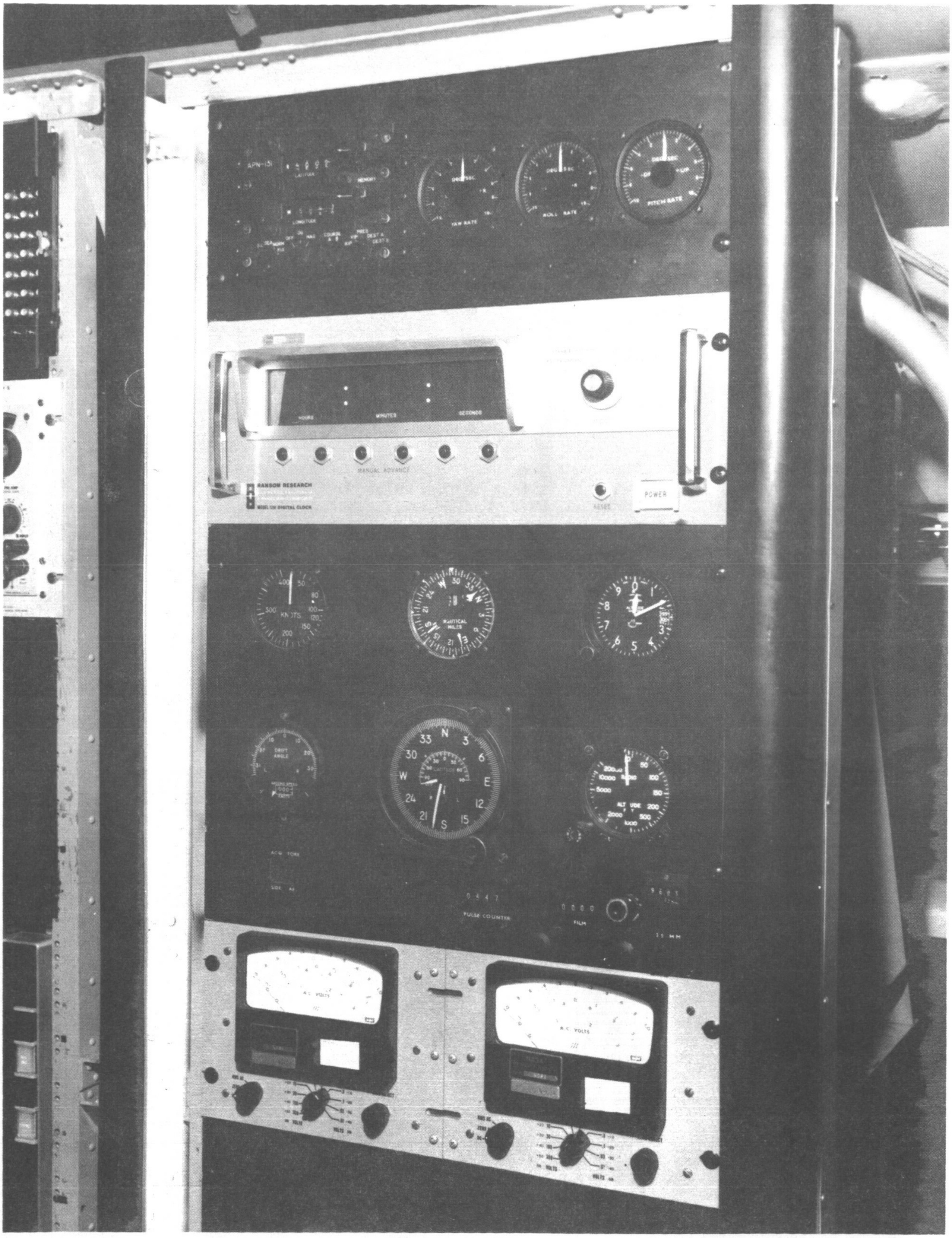


Fig. 14 FLIGHT PARAMETERS DISPLAY PANEL

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Fig. 15 FLIGHT PARAMETERS RECORDING CAMERA

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S-65-15258

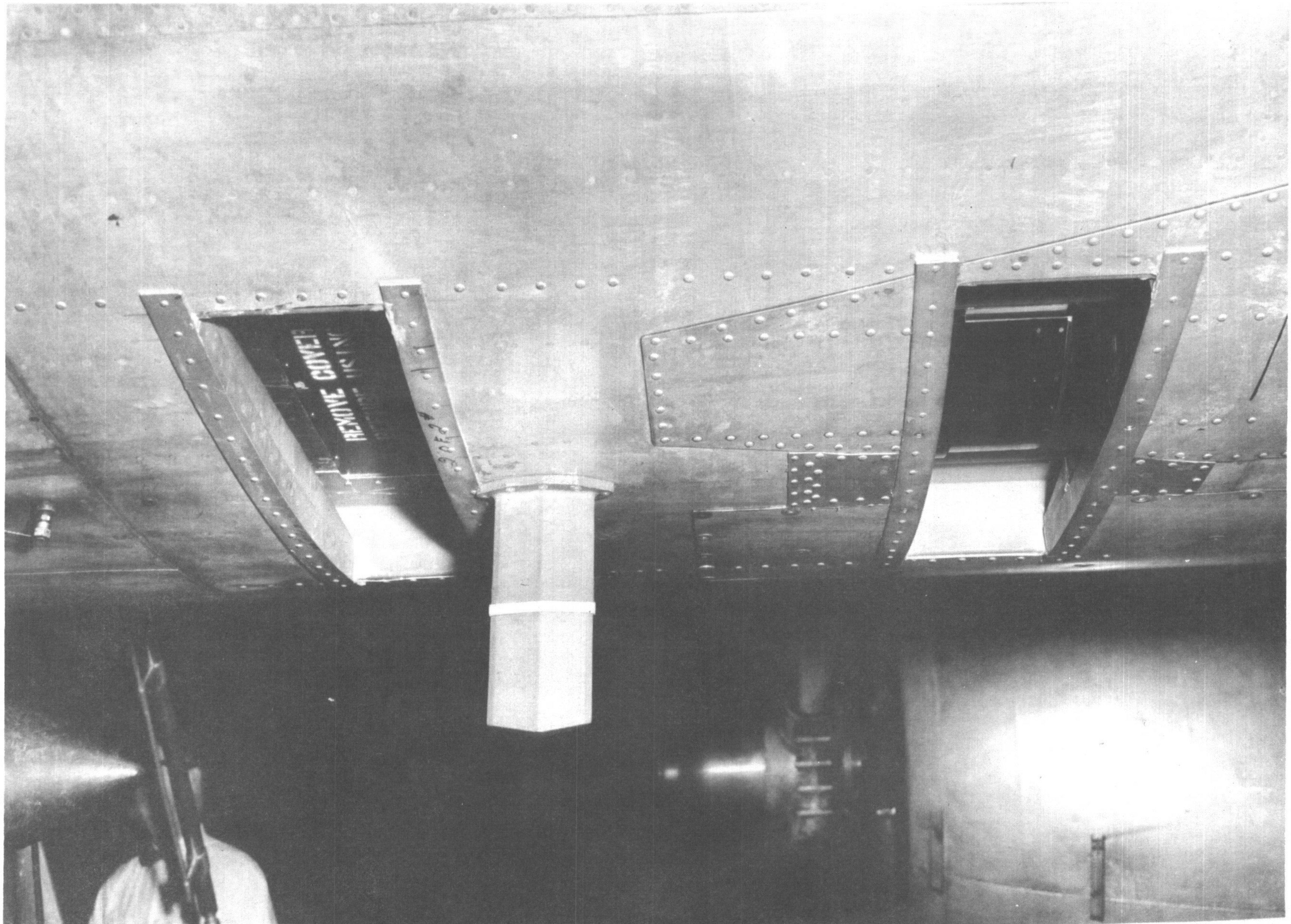


FIGURE 16. INFRARED SENSOR VIEW PARTS

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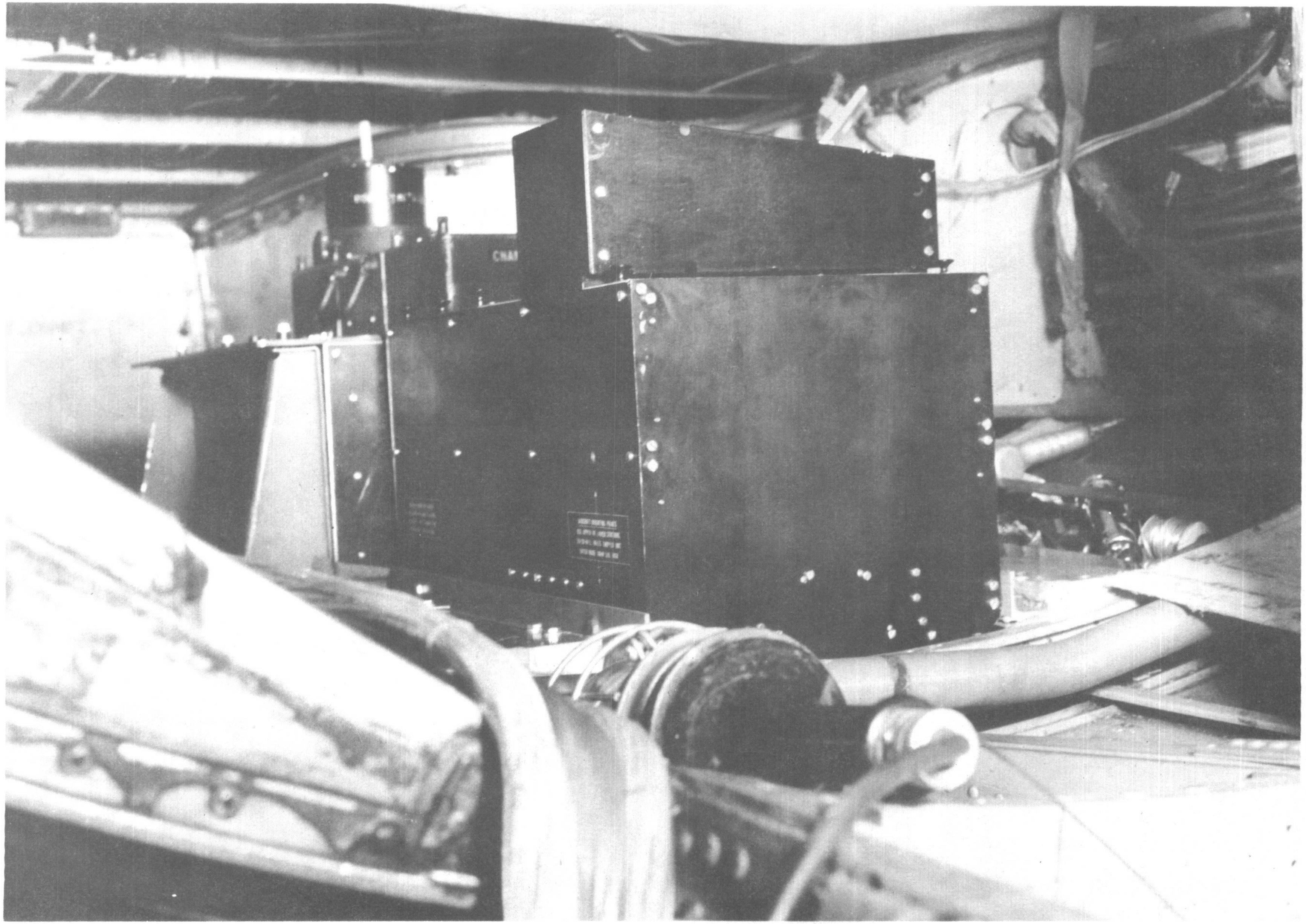

FIGURE 17. INFRARED SENSOR EQUIPMENT INSTALLED IN FORWARD BAGGAGE COMPARTMENT

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T-11 MAPPING CAMERA AND A-28 GYRO-STABILIZED MOUNT

NASA
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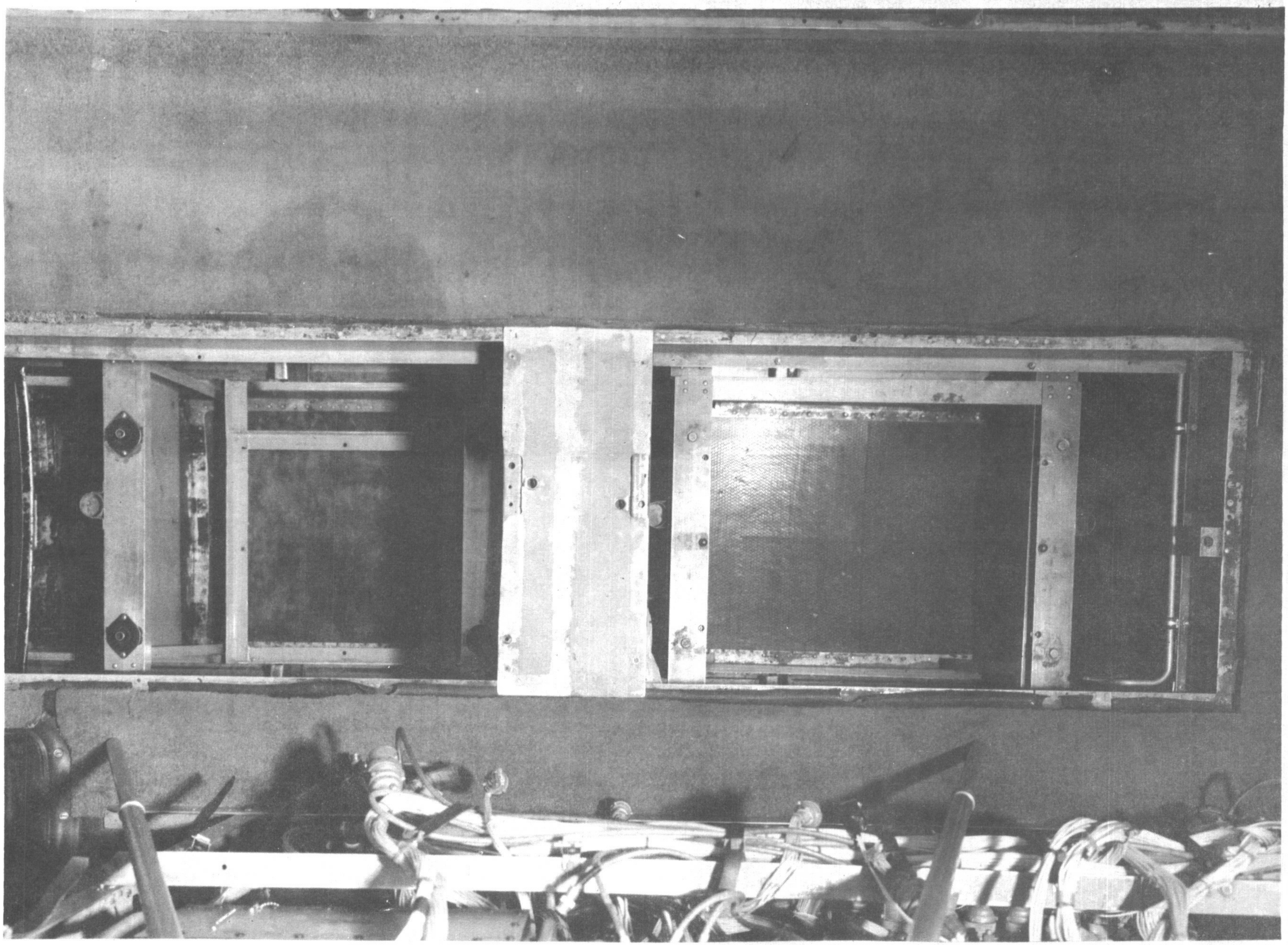

FIGURE 19. EXPERIMENT BAYS RESERVED FOR MULTISPECTRAL CAMERA AND INFRARED SPECTROMETER

# NASA REMOTE SENSING INVESTIGATOR TEAMS

| AREA OF INVESTIGATION | CURRENT TEAM LEADERS | ORGANIZATIONS INVOLVED |
|---|---|---|
| PANORAMIC & CARTOGRAPHIC PHOTOGRAPHY | J. GILLIS | U.S. ARMY (GIMRADA) |
| MULTISPECTRAL PHOTOGRAPHY | J. CRONIN | USAF (A.F.C.R.L.) |
| | J. ADAMS | J.P.L. |
| | R. COLWELL | UNIV. CALIF. (BERKELEY) |
| | W. TIFFT | UNIV. ARIZONA |
| I.R. IMAGERY, SPECTROSCOPY & PHOTOMETRY | R. LYON | NASA / AMES |
| | W. FISCHER | U.S.G.S. |
| | S. GAWARECKI | U.S.G.S. |
| | J. CONEL | J.P.L. |
| RADAR IMAGERY AND ALTIMETRY AND R.F. REFLECTIVITY | R.K. MOORE | UNIV. KANSAS |
| | B. SCHEPS | U.S. ARMY (GIMRADA) |
| | W. BROWN, JR. | J.P.L. |
| | W. PEAKE | OHIO STATE UNIV. |
| | A.R. BARRINGER | BARRINGER RESEARCH LTD. |

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3-8-65

FIGURE 20 SUMMARY OF INVESTIGATOR TEAMS PARTICIPATING IN THE NASA FEASIBILITY TEST PROGRAM

| AREA OF INVESTIGATION | CURRENT TEAM LEADERS | ORGANIZATIONS INVOLVED |
|---|---|---|
| PASSIVE MICROWAVE RADIOMETRY & IMAGERY | F. BARATH | J.P.L. |
| | R. SPEED | J.P.L. |
| | D. JONES | BRIGHAM YOUNG UNIV. |
| ABSORPTION SPECTROSCOPY (REMOTE TRACE ELEMENT DETECTION) | A.R. BARRINGER* | BARRINGER RESEARCH LTD. |
| | T.S. LOVERING* | U.S.G.S. |
| | R. GARRELS* | HARVARD UNIV. |
| GRAVITY GRADIENT SENSORS | L. THOMPSON | GEOSPACE CORP. |
| | R. BOCK | AMER. BOSCH ARMA |
| | P. SAVET | GRUMMAN AVIATION |
| GEOLOGIC APPLICATIONS | W.T. PECORA* | U.S.G.S. |
| | M. KLEPPER* | U.S.G.S. |
| OCEANOGRAPHIC APPLICATIONS | C. BATES* | U.S. NAVY (N.O.O.) |
| | G. EWING | WOODS HOLE O.I. |

(*) = TO BE ACTIVATED IN THE NEAR FUTURE

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FIGURE 20 CONTINUED

| AREA OF INVESTIGATION | CURRENT TEAM LEADERS | ORGANIZATIONS INVOLVED |
|---|---|---|
| GEOGRAPHIC APPLICATIONS | J. GILLIS<br>E. PRUITT | U.S. ARMY (GIMRADA)<br>U.S. NAVY (O.N.R.) |
| AGRICULTURE & FORESTRY APPLICATIONS | H. RODENHISER<br>R. SHAY<br>R. COLWELL | U.S.D.A.<br>PURDUE UNIV.<br>UNIV. CALIF. (BERKELEY) |
| REMOTE SENSING TEST SITE COMMITTEE | R. REEVES<br>P.C. BADGLEY<br>W. FISCHER | NASA HDQ.<br>NASA HDQ.<br>U.S.G.S. |
| AIRCRAFT COORDINATION | L. CHILDS<br>M. BADER | NASA / MSC<br>NASA / AMES |
| DATA HANDLING | J. GILLIS<br>B. SCHEPS<br>M. HOLTER | U.S. ARMY (GIMRADA)<br>U.S. ARMY (GIMRADA)<br>UNIV. MICHIGAN |
| GROUND "TRUTH" AND STATISTICAL SAMPLING | J. FRIEDMAN<br>W. HEMPHILL<br>E.H. WHITTEN<br>W.C. KRUMBEIN | U.S.G.S.<br>U.S.G.S.<br>NORTHWESTERN UNIV.<br>NORTHWESTERN UNIV. |

(* = TO BE ACTIVATED IN THE NEAR FUTURE)

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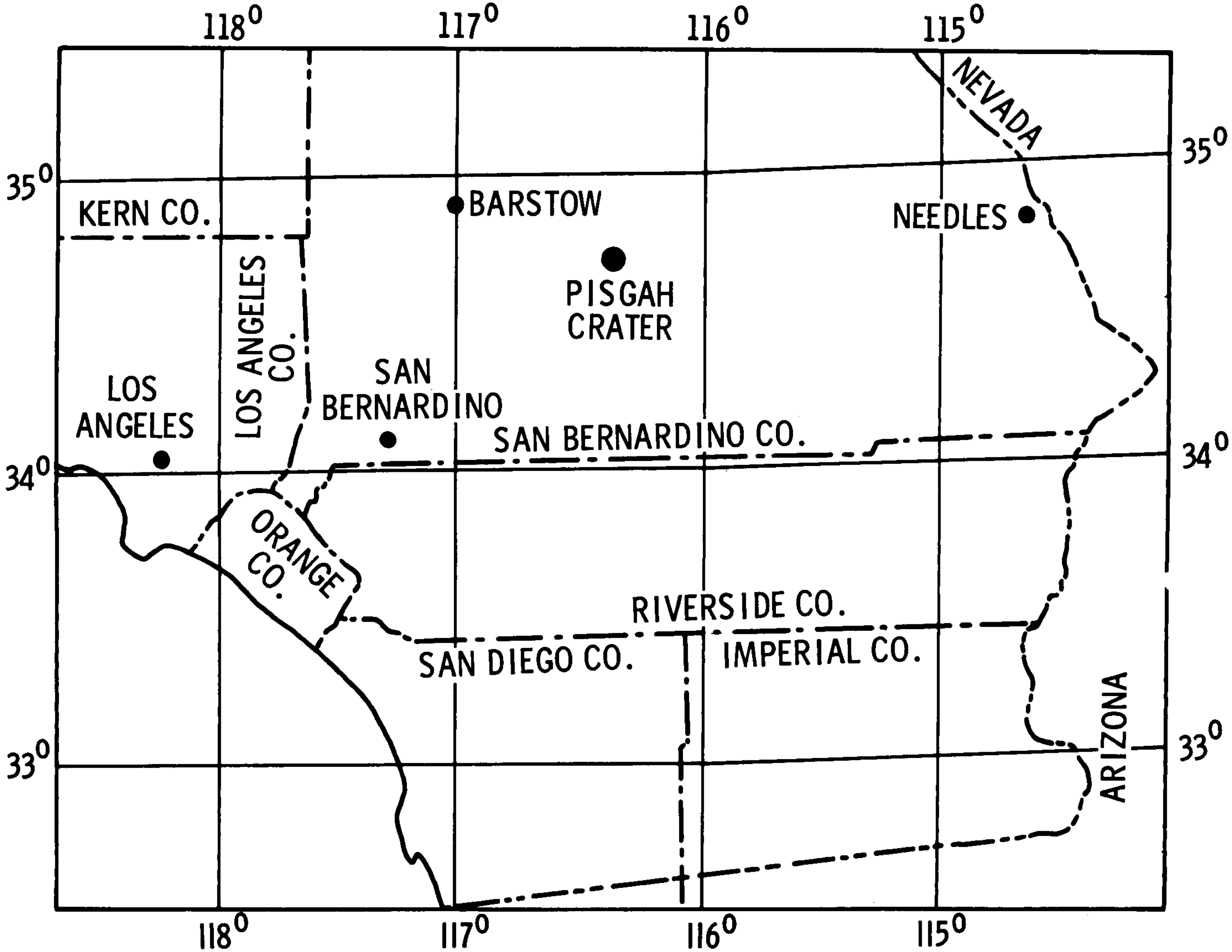
3-8-65

FIGURE 20 CONTINUED




**INDEX MAP SHOWING THE LOCATION OF THE PISGAH CRATER AREA, CALIFORNIA**

FIGURE 21

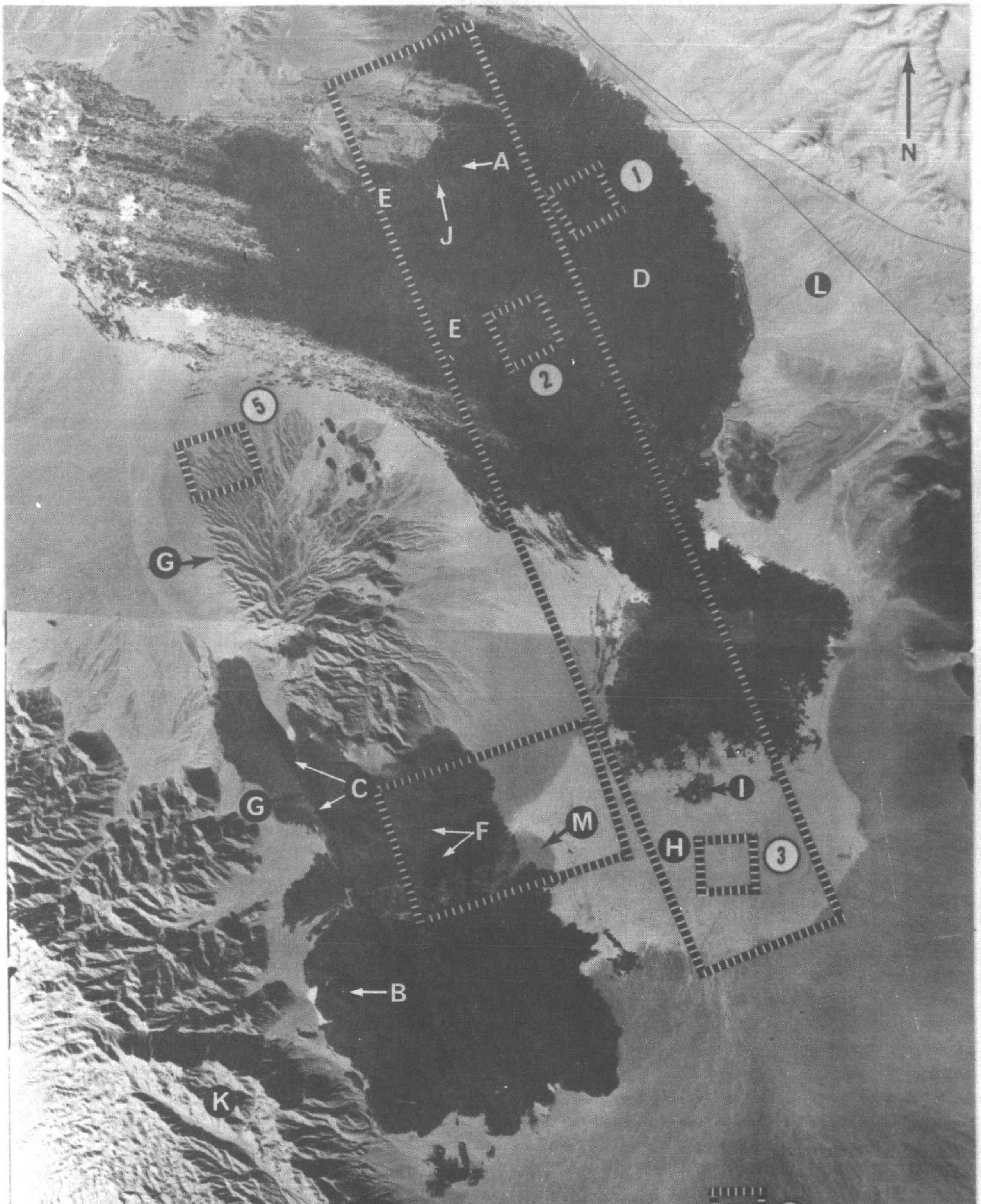



FIGURE 22 Index Aerial View of Pisgah Crater Area

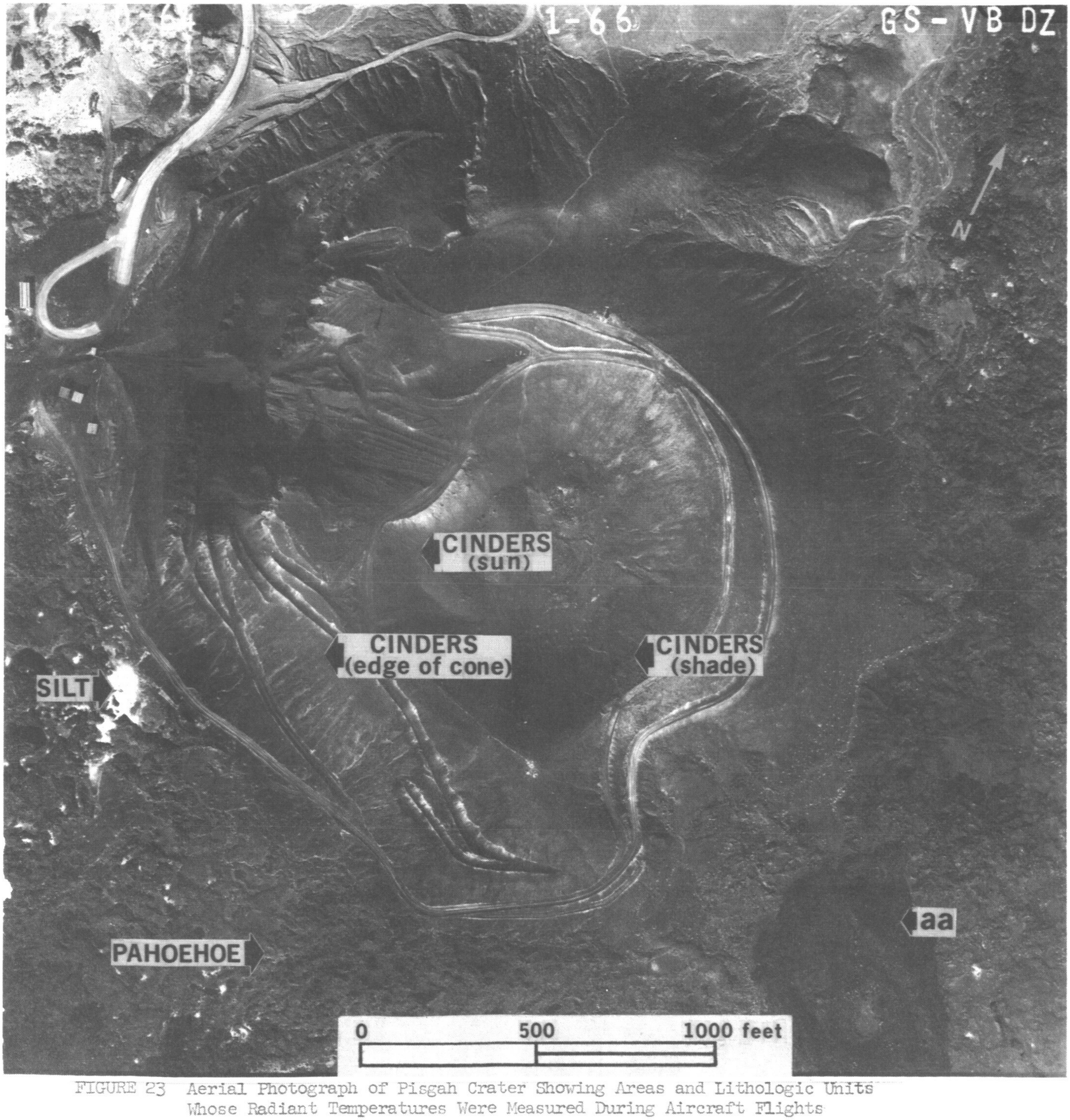



FIGURE 23 Aerial Photograph of Pisgah Crater Showing Areas and Lithologic Units Whose Radiant Temperatures Were Measured During Aircraft Flights

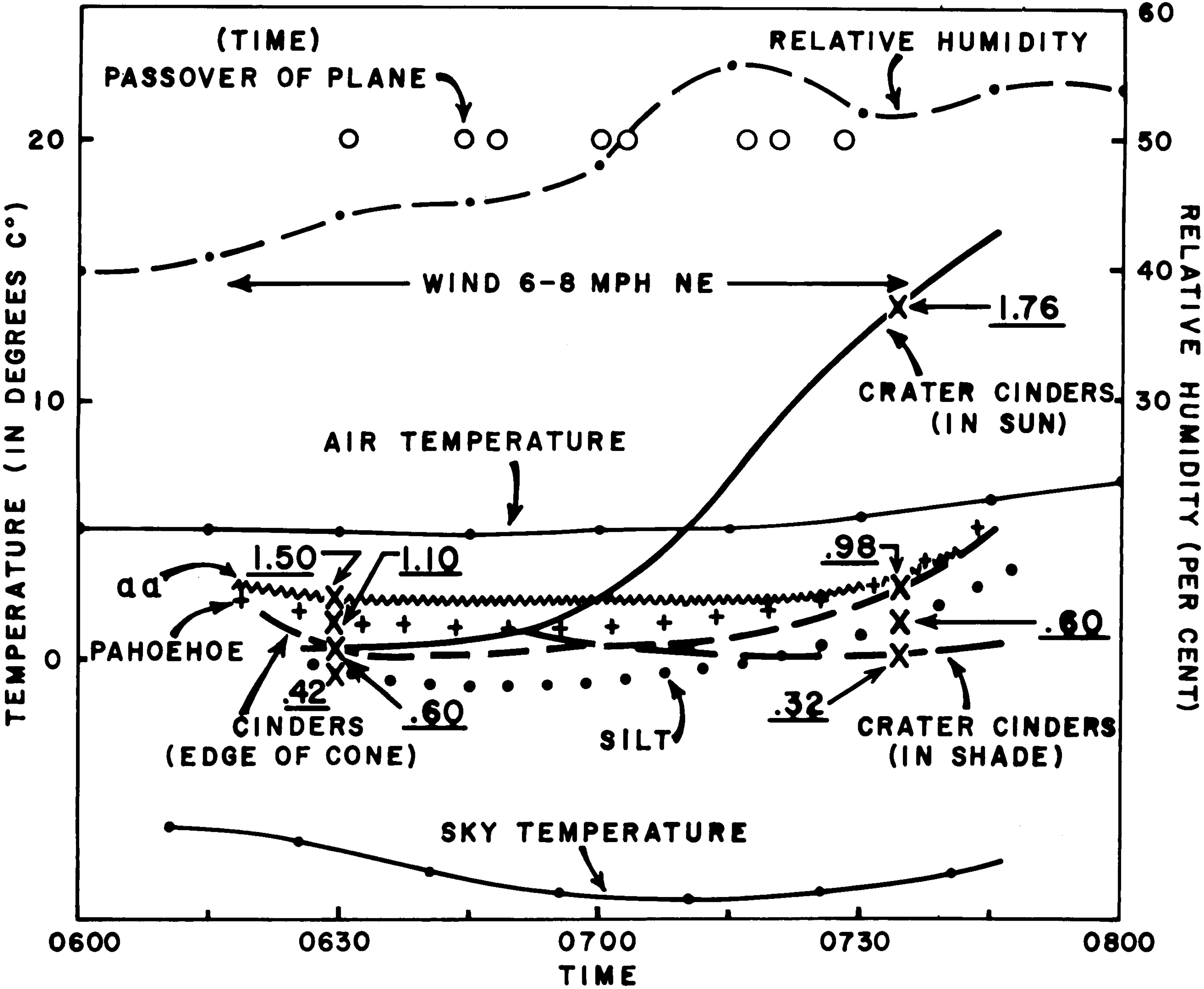



FIGURE 24 Temperature Variations of Lithologic Units During Infrared Imaging Overflights

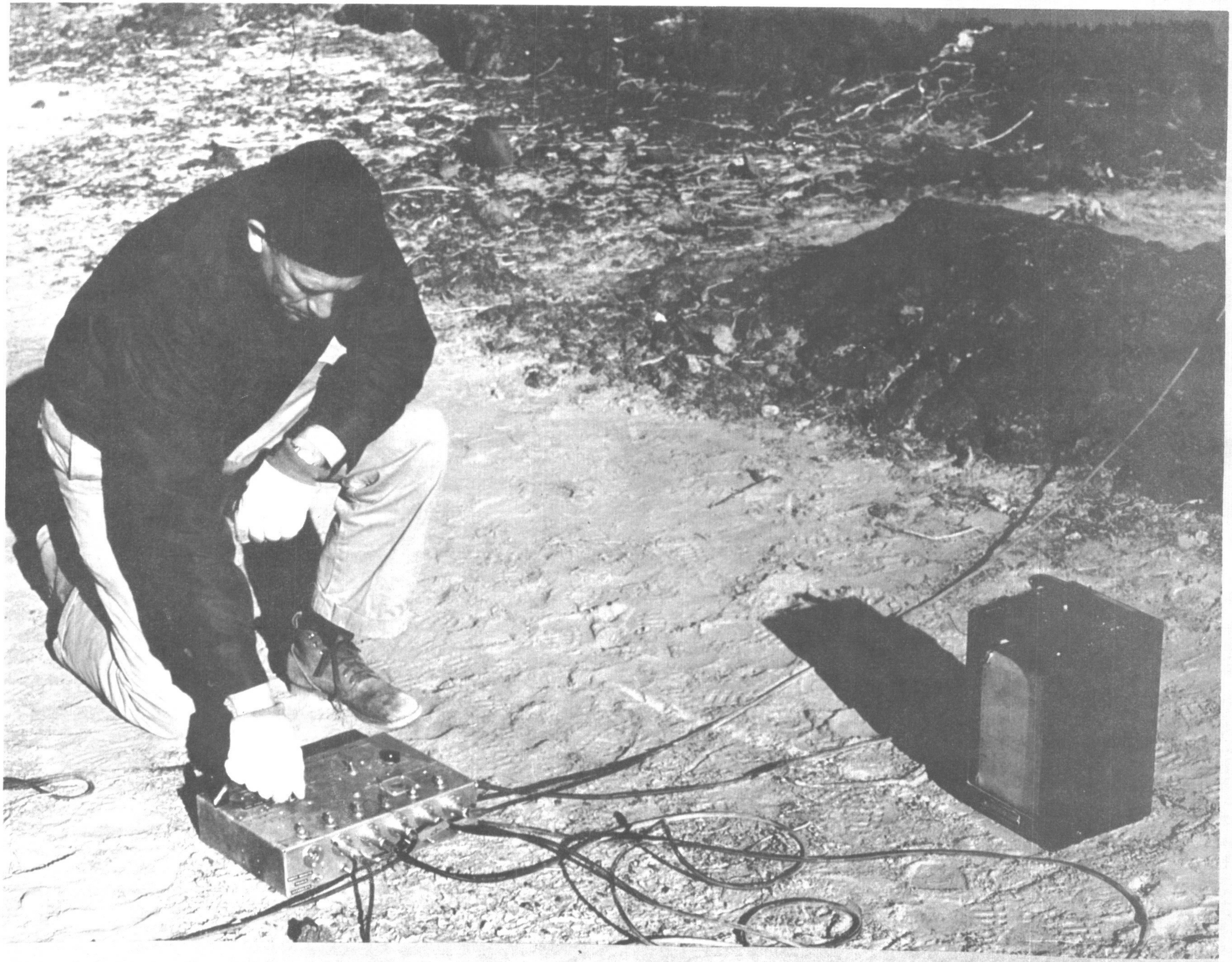
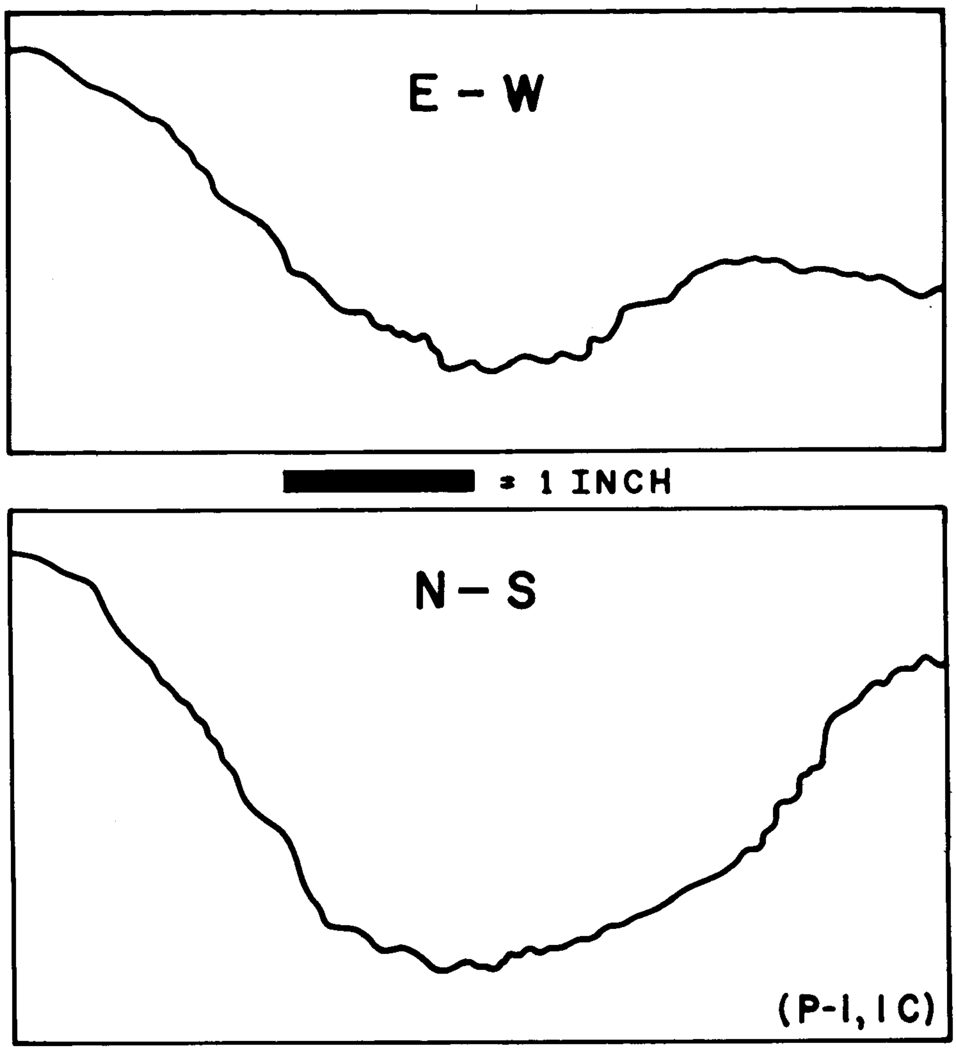


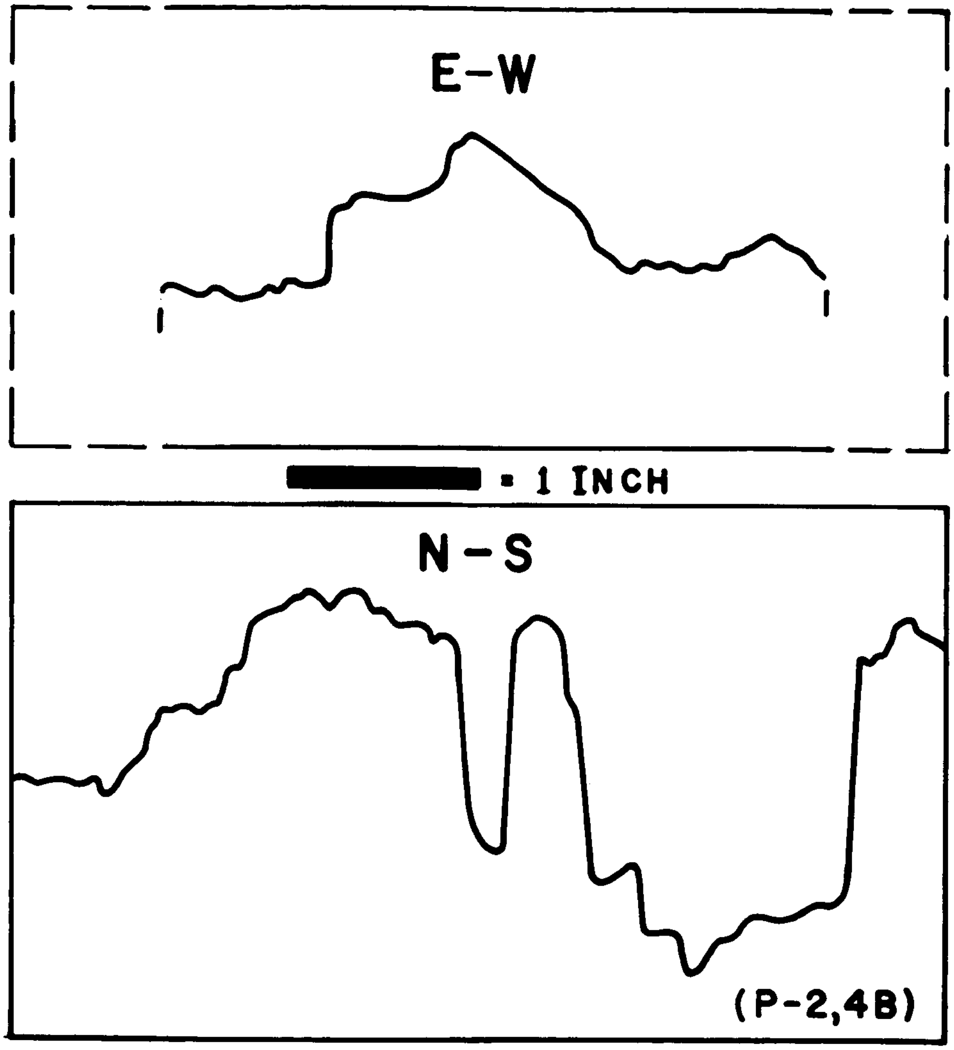
FIGURE 25 Monitoring a Thermistor Array System to Determine Ground Temperatures During Infrared Aerial Survey of Pisgah Crater Area, Feb. 12-14, 1965

FIGURE 26 Taping a 225 $Ft^2$ Sampling Grid to Obtain Preliminary Hand Specimens of Pahoehoe Surface Material for Laboratory Study



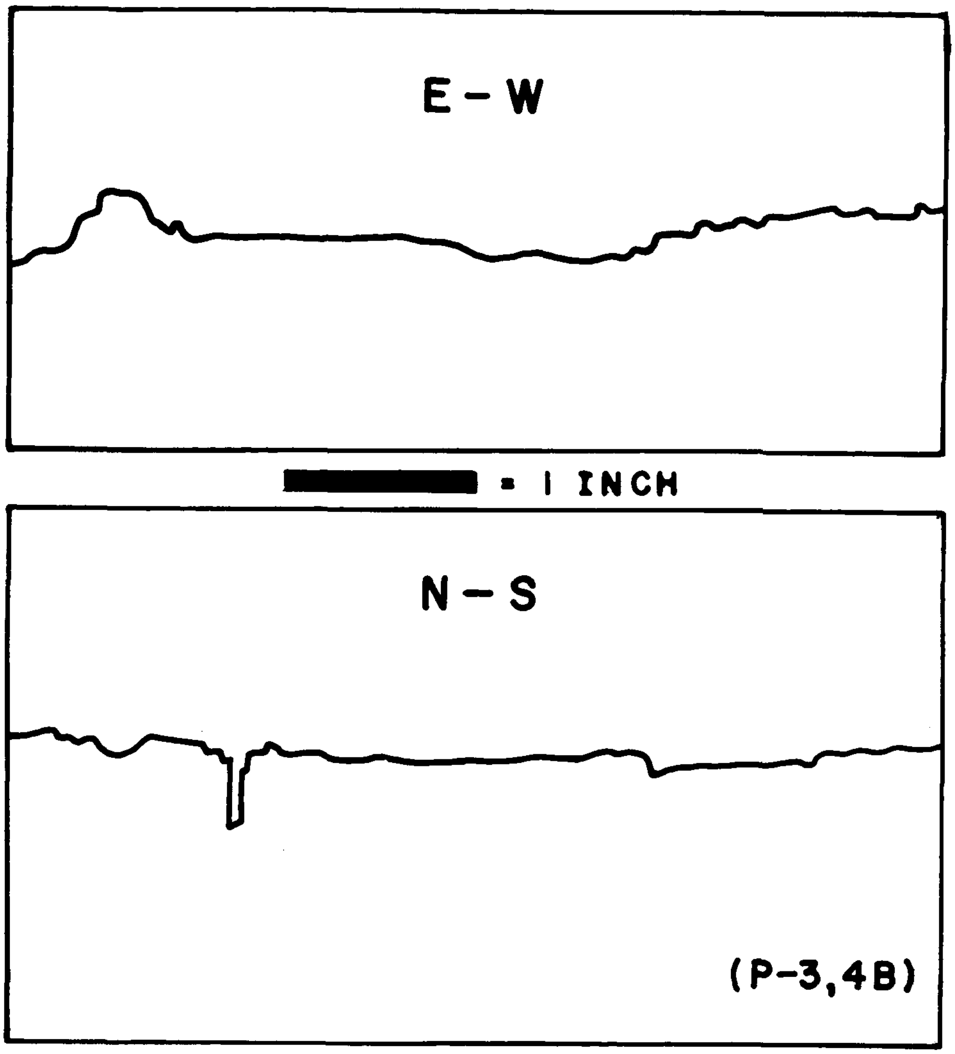

TYPICAL PAHOEHOE SURFACE

FIGURE 27 Profiles of Typical Surfaces of Five Lithologic Units for Which Preliminary Samples Were Collected



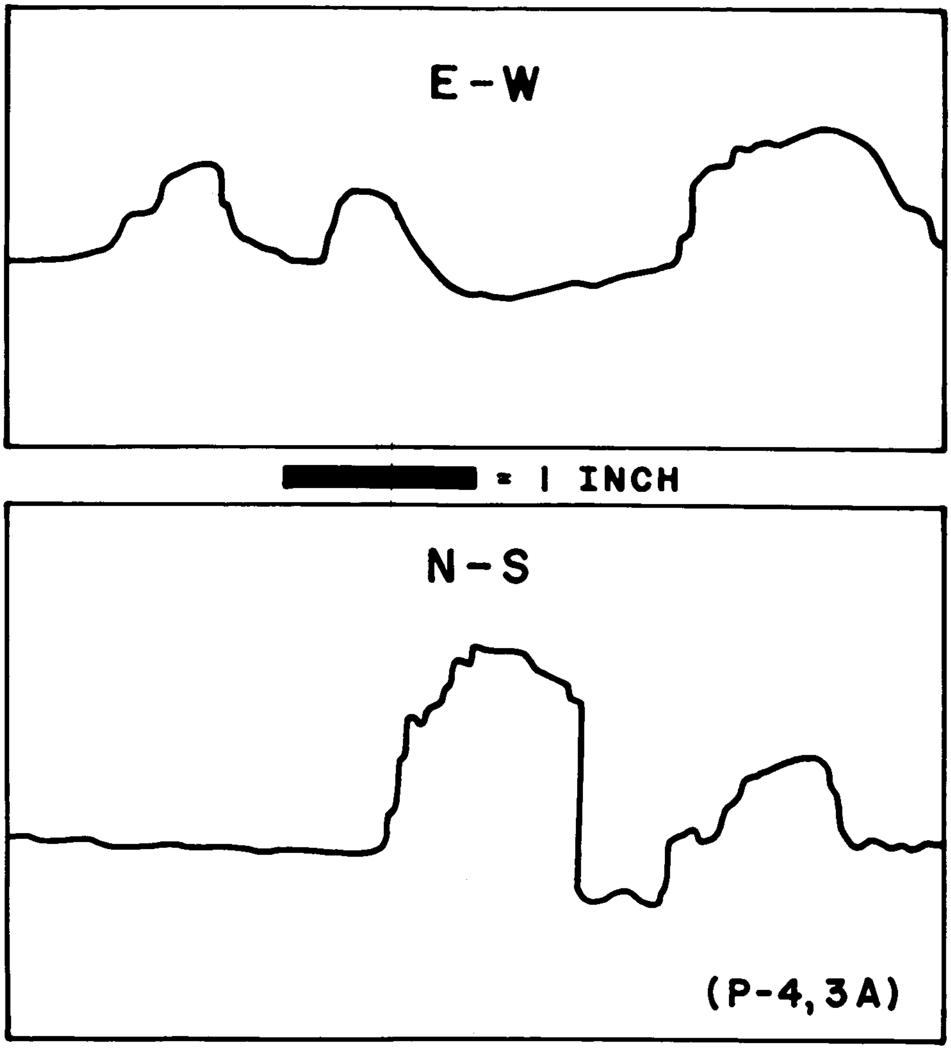

TYPICAL aa SURFACE

FIGURE 27 CONTINUED



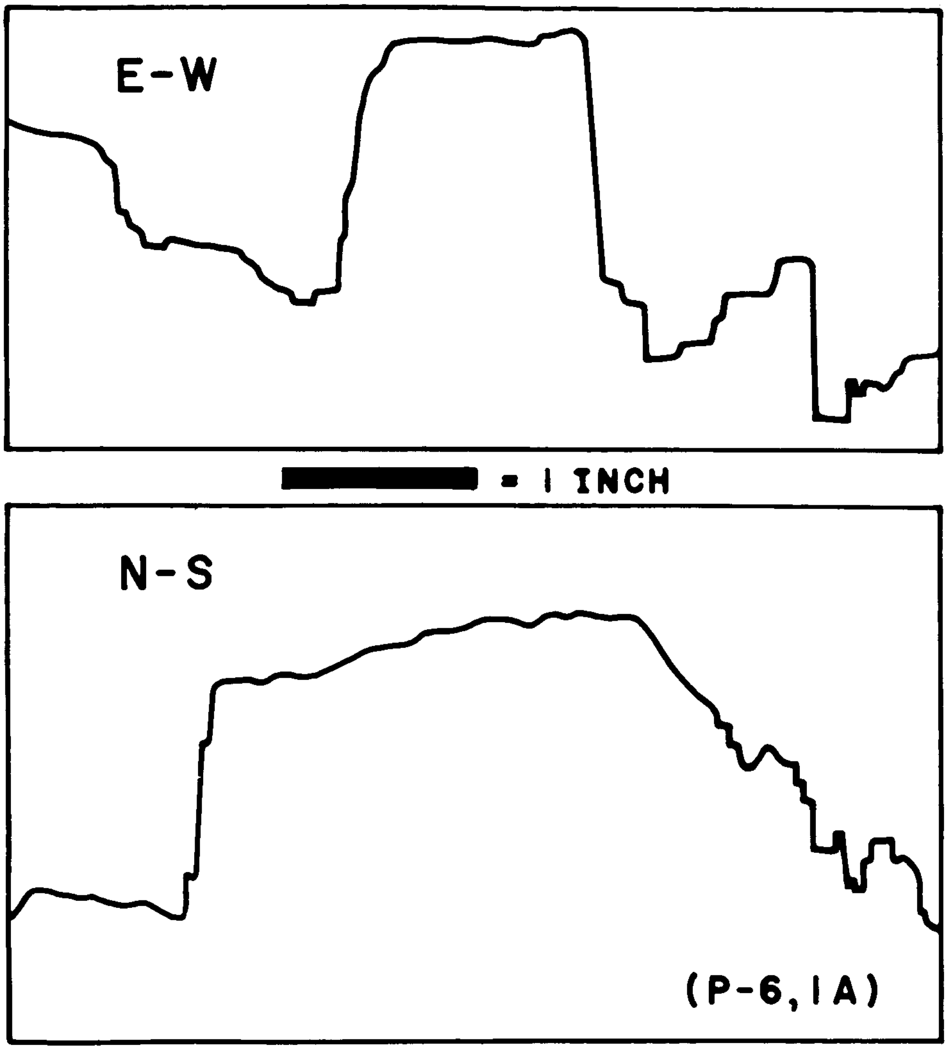

TYPICAL SILTY CLAY OF PLAYA SURFACE

FIGURE 27 CONTINUED




TYPICAL FRAGMENTS ON PLAYA SURFACE

FIGURE 27 CONTINUED




TYPICAL VOLCANIC EJECTA SURFACE

FIGURE 27 CONTINUED

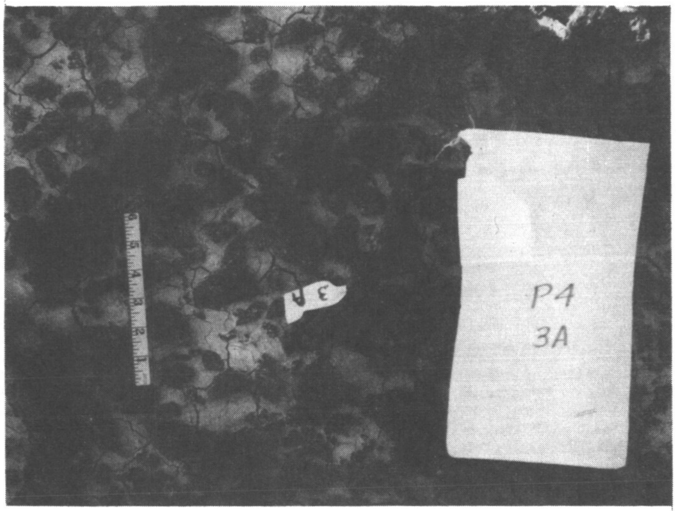



FIGURE 28 Angular, Vesicular Basalt Fragments Distributed in Rough Polygonal Patterns on the Mud-Cracked Calcareous Silty-Clay Surface of Lavic Lake Playa

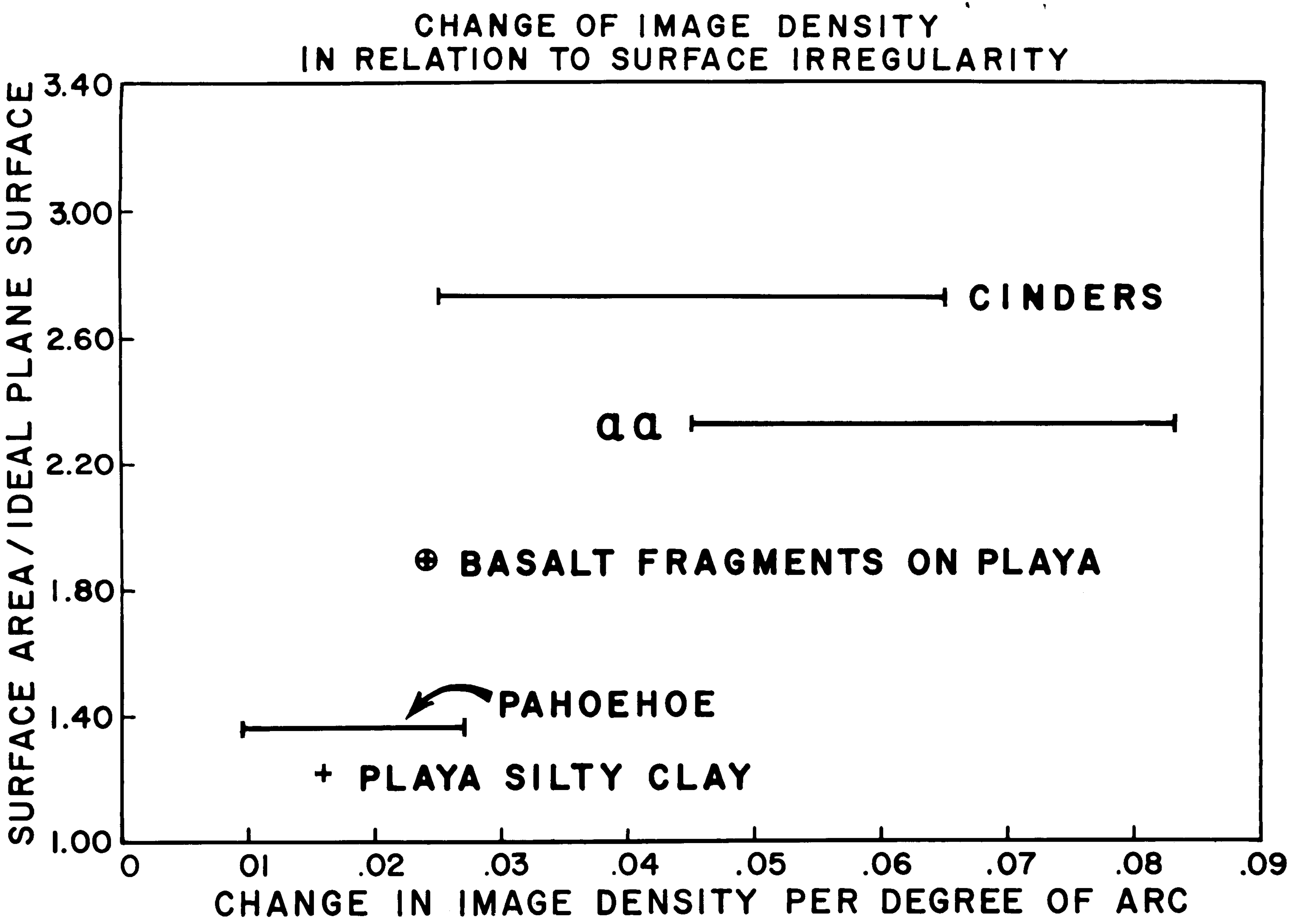



FIGURE 29 Change in Image Density in Relation to Surface Irregularity

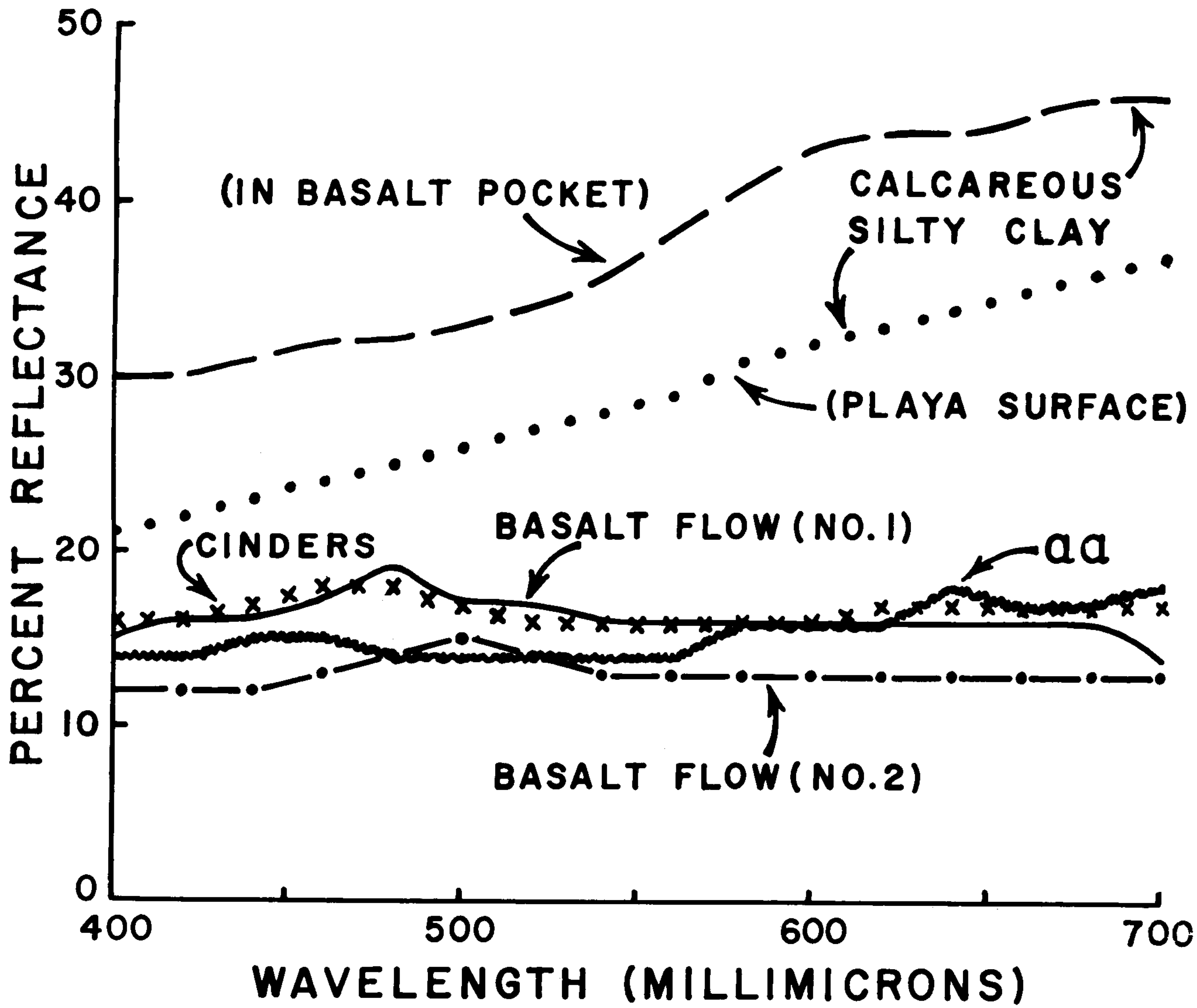



FIGURE 30 Reflectance of Lithologic
Units in the Visible Spectrum

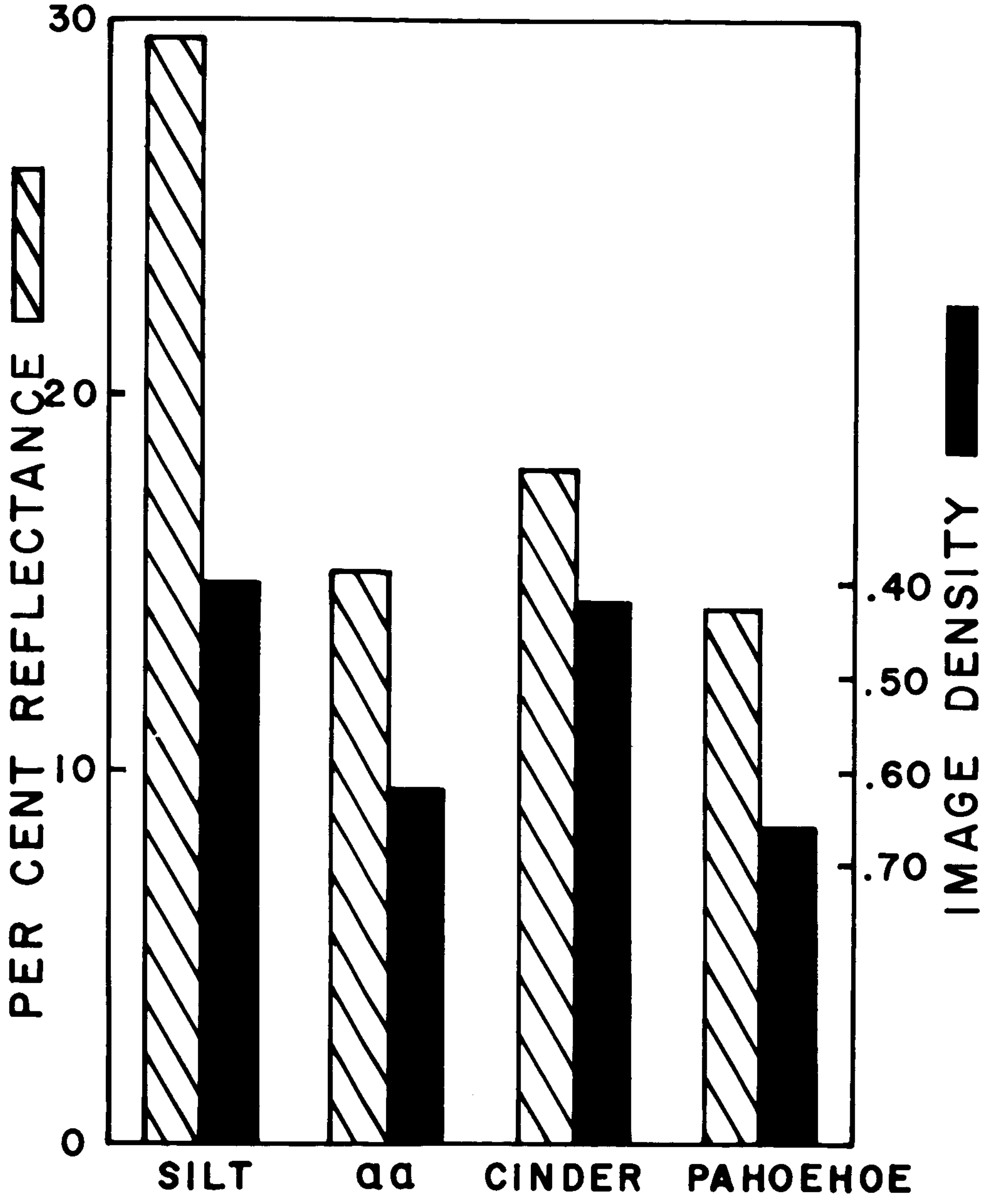



FIGURE 31 Relationship of the Reflectance of Various Materials, as Determined by Colorimeter Measurement, To Relative Infrared Emission, Measured and Expressed as Film Density as Recorded on Infrared Image Produced at 14:10, February 13, 1965

FIGURE 32 Interferometer Spectrometer Used for Field Measurement of the Spectral Energy Distribution of Infrared Radiation (5-15 Micron) Emitted from Various Rock Surfaces